BMJ Open

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Journal:	*BMJ Open*
Manuscript ID	bmjopen-2018-026275
Article Type:	Research
Date Submitted by the Author:	30-Aug-2018
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Keywords:	Muscle strength, Hand grip strength, Dietary intake, Adolescents, Physical activity

Research article

Dietary intake, physical activity and muscle strength among adolescents: the Malaysian Health and Adolescents Longitudinal Research Team (MyHeART) study

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Word Count, excluding title page, abstract, references, figures and tables: 3379 words.

Tables: 3

Funding Statement: This study was supported by funding received from the University Malaya's Research Programme (UMRP022A-14HTM) and Postgraduate Research Fund (PG026-2016A).

Funding

University of Malaya Research Grant (UMRP022A-14HTM), UMSC grant cycle 1-2016 and all the school children who participated in this study. The funding bodies did not contribute to the design of the study, data collection, analysis, or interpretation of data.

Disclosure: The authors declare that they have no conflict of interests.

Author Contributions/ Statement of authorship: AK Ng, HA Majid and NN Hairi carried out the data analysis. AK Ng drafted the manuscript. HA Majid and MY Jalaludin contributed in the design of the study and data collection. All authors contributed to the final manuscript write up.

Ethics approval and consent to participate

Ethical approval was obtained from the Medical Ethics Committee, University Malaya Medical Centre (MEC Ref. No: 896.34). The National Medical Research Register number is 14-376-20486. Participation in the study was voluntary and written informed consent and ascent for participation in the study was obtained from the parents or guardian as well as the participants.

Title: Dietary intake, physical activity and muscle strength among adolescents: the Malaysian Health and Adolescents Longitudinal Research Team (MyHeART) study

ABSTRACT

Objective: To examine the role of dietary intake and physical activity in muscle strength among adolescents.

Design: Cross-sectional analysis.

Setting: The Malaysian Health and Adolescents Longitudinal Research Team (MyHeART) study.

Participants: Fifteen-year-old secondary school children who have given consent and who participated in the MyHeART study in 2014.

Primary outcome measure: Muscle strength was measured in relation to dietary intake (energy and macronutrients) and physical activity by using a hand grip dynamometer.

Results: Among the 1012 participants (395 male; 617 female), the hand grip strength of the males was higher than that of the females (27.08 kg vs 18.63 kg; $p<0.001$). Also, males were more active (2.43 vs 2.12; $p<0.001$) and consumed a higher amount energy (2047 kcal vs 1738 kcal, $p<0.001$), carbohydrate (280.71 g vs 229.31 g; $p<0.001$) and protein (75.69 g vs 66.07 g; $p<0.05$). After controlling for ethnicity, place of residency, body mass index (BMI), percentage body fat and waist circumference, there was a positive relationship between hand grip strength and the intake of energy ($r=0.143$; $p=0.005$), carbohydrate ($r=0.158$; $p=0.002$) and fat ($r=0.124$; $p=0.014$) and the physical activity score ($r=0.155$; $p=0.003$) for males. However, this relationship was not observed among females.

Conclusions: Energy, carbohydrate, fat intake and physical activity score were positively correlated with hand grip strength in males but not in females.

Keywords: Muscle strength, Hand grip strength, Dietary intake, Physical activity, Adolescents

ARTICLE SUMMARY

Article focus

- Muscle strength, as measured by hand grip strength, is an important indicator of health-related outcomes among adolescents.
- The potential effect of dietary intake on the muscle strength of adolescents is investigated.

Key messages

- After controlling for ethnicity, place of residency, body mass index, percentage body fat and waist circumference, the results show that greater intake of energy carbohydrate and fat and a higher physical activity score are associated with greater hand grip strength for males. However, this was not observed for females.
- The results also show that energy intake and physical activity score have positive effects on male hand grip strength after controlling for body mass index.

Strengths and limitations of this study

- The main strengths of this study are that it used a large sample of adolescents and the standardised measurement of muscle strength.
- This study is the first to investigate the association between dietary intake, physical activity and muscle strength among adolescents in Asia.
- The main limitations of this study are that the sample covers a limited age range and the cross-sectional design of the study does not allow any causality interpretations.

INTRODUCTION

Recent research has paid much attention to poor muscles strength among adolescents and its association with adverse health-related outcomes, including cardiovascular disease,[1] poorer metabolic profile,[2-4] obesity[5 6] and musculoskeletal pain[7] as well as premature death from any cause.[1] A recent study suggested that improving muscular fitness and adhering to the Southern European Atlantic Diet (SEADiet) helps to minimise cardiovascular risk among Portuguese adolescents.[8] The study emphasised the importance of the synergistic effect of a healthy dietary intake on high muscle strength. Another study showed that healthy adolescents who are physically active and have higher cardiorespiratory and higher muscular fitness, have lower adipocytokines.[9] In contrast, a cohort study reported that the findings do not support the idea that low muscle strength is a risk factor for future musculoskeletal pain.[7]

Furthermore, a cross-sectional study among adolescents in a city of southern Brazil reported a prevalence of low muscle strength of 47% among the study population.[10] Moreover, most studies have suggested that there is a declining trend of muscle strength among adolescents over time[11-14] except a study from Columbia in South America[15] that indicated otherwise. The study from Columbia, a middle-income country, also found that, adolescents have a lower hand grip strength compared to those in high-income countries.[15] Similarly, a preliminary finding from the MyHeART study showed that Malaysian adolescents have a lower handgrip strength than those in other countries.[11 16 17] However, it was not possible to categories hand grip strength of the Malaysian adolescents based on the cutoff values used[10] as there were no available normal values for Asian adolescents. Moreover, the published cutoff values should not be used as the reference standard for Asian populations because most Asian are not able to achieve the published cutoff values.[18]

Issues pertaining to unhealthy dietary intake[19] and low physical activity[20] among adolescents are well documented worldwide. In fact, recent studies have shown that unhealthy dietary intake and/or low physical activity is associated with poor muscle strength status among adolescents.[8 21] However, in respect of the effect of implementing changes to dietary intake and exercise, an experimental study on adolescents showed that milk supplementation together with resistance training does not change body composition.[22] Nevertheless, the study argued that energy intake play a role as a moderator in the relationship between body composition, resistance training and protein intake, which increases muscle mass and strength.[22] According to the result of a cohort study where balanced protein-energy supplementation was given to pregnant women and children less than six years of age and the offspring were later followed up at the adult stage, energy intake and physical activity are positively associated with muscle strength at the adult stage.[23] The cross-sectional study, which was conducted among European adolescents, found that specific amino acids are associated with muscle strength; however, these relationships disappear when carbohydrate is controlled for.[17] Besides studies on the effect of nutrients, some studies

have investigated the relationship between the Mediterranean diet and muscle strength. However, a study on Spanish adolescents found no significant association between muscle strength and adherence to the Mediterranean diet.[24] Nevertheless, the evidence on the association between the Mediterranean diet and muscle strength is scarce and inconclusive at this point of time.[25]

To date, the relationship between dietary intake, particularly energy and macronutrients, physical activity and muscle strength among adolescents is not well understood. Moreover, to the best of our knowledge, only a limited number of studies have investigated the association between muscle strength, dietary intake and physical activity among adolescents, particularly in Asia. Therefore, the purpose of this paper is to examine the association between hand grip strength, dietary intake and physical activity among adolescents in Malaysia.

METHODS

This paper is based on secondary analysis of a cross-sectional study derived from the Malaysian Health and Adolescents Longitudinal Research Team (MyHeART) study. Details of the MyHeART study protocol have been published previously.[26] In 2014, 1230 adolescents were recruited for the MyHeART study. Out of the total participants in 2014, 1012 (82.3%) with valid data on gender, BMI, dietary intake (energy, carbohydrate, protein, fat), hand grip strength and physical activity score were involved in the analysis for this paper. The MyHeARTs study was originally approved by the Ethics Committee of the University Malaya Medical Centre (MEC Ref. No. 896.34).

Muscle strength

Hand grip strength has been shown to have moderate to strong validity and high reliability in tests for upper body and lower body strength in adolescents.[27] Moreover, hand grip strength has been found to be valid, reliable and feasible for school setting.[28] Therefore muscle strength was assessed by using hand grip strength. A calibrated hand dynamometer (Jamar, Sammons Preston Rolyan, Illinois, US), whose unit of measurement is the kilogram, was used in the assessment of hand grip strength. The strength of the dominant and the non-dominant hand was recorded. Prior to the measurement, the dynamometer was calibrated. Then, it was adjusted for different hand sizes. All measurements were done by trained research assistants.

Dietary intakes

Dietary intake was assessed by using a 7-day diet history. The diet history is the best method by which to estimate adolescents' intakes because they can better recall what they have eaten and drunk and can thus reveal more about their overall intakes.[29] This method also shows less variation in dietary assessment from the epidemiological perspective[30] and is more representative of adolescents' habitual intakes than other methods.[31 32] The 7-day diet history was collected by a qualified dietitian. The *Nutrient Composition of Malaysian Food* (4th edition)[33] was used to

calculate energy and macronutrient intakes and the values were entered into the Nutritionist ProTM database (Axxya Systems, US).[33] The intakes from food items and recipes that could not be found in the *Nutrient Composition of Malaysian Food* were calculated on the basis of the details provided by the food packaging and the recipe. These calculations were then entered into the database by adjusting them based on standard recipes (per serving size). After the diet history had been analysed, 10% of the data were randomly cross-checked by an independent qualified dietitian where the margin of error was set at less than 5%.

Physical activity score

A Malay version of the validated physical activity questionnaire for older children (PAQ-C) consisting of 10 items was used to obtain the physical activity level of the adolescents over the past 7 days. The PAC-Q questionnaire has been shown to be valid and to have good internal consistency.[34-36] The first item was used to assess the type and frequency of sports and/or dance activities that the adolescents performed. The second to eighth were used to assess the activity of the adolescents during physical education classes, recess, lunchtime, immediately after school, in the evenings, at the weekend and leisure time. A five-point Likert scale [1 (lowest) to 5 (highest)] was used for the second to eighth items. The ninth item was used to assess their physical activity frequency. The tenth item was used to gather information on any unusual activities that the adolescents undertook during those 7 days. The results obtained from the PAQ-C were categorised following Crocker et al into low (<2.33), moderate (2.33-3.66) and high (>3.66).[37]

Anthropometric measures

Body weight was measured using a digital electronic weighing scale (Seca 813, Seca, UK) and recorded to the nearest 0.1 kg. Height was measured without socks and shoes by using a calibrated vertical stadiometer (Seca Portable 217, Seca, UK) and recorded to the nearest 0.1 cm. Body mass index was calculated as weight in kilograms divided by the square of height in metres. Waist circumference (midpoint between the lowest rib margin and the iliac crest) was measured by using a non-elastic measuring tape (Seca 201, Seca, UK) and recorded to the nearest 0.1 cm. Percentage body fat was measured by using a bioelectric impedance analyser (SC-240, Body Composition Analyser, Tanita Europe BV, The Netherlands).

Sociodemographic measures

Sociodemographic measures were collected via parental and student questionnaires which included questions on age, ethnicity and place of residency.

Statistical analyses

Analyses were performed using the Statistical Package for Social Sciences software for Windows (version 22.0 Chicago, IL, US) and the significance level was set at $p<0.05$. The analyses were performed separately by gender. Normality and skewness tests were used to assess normal distribution. All variables showed a normal distribution, except for weight, waist circumference and BMI. Data were presented as means and standard deviations for normally distributed continuous variables, medians and interquartile ranges (IQRs) for non-normally distributed continuous variables and percentages for categorical variables. The independent t-test was used to examine gender differences for normally distributed variables and the Mann-Whitney U test was used for non-normally distributed variables. The association between hand grip strength and (i) energy intake, (ii) macronutrient intake and (iii) physical activity score were assessed by using Pearson's correlation coefficient. The hand grip strength of the dominant hand was entered as the dependent variable and (i) energy and macronutrient intake and (ii) physical activity score were entered as the independent variables while controlling for ethnicity, place of residency, BMI, percentage body fat and waist circumference. In addition, linear regression was used to investigate whether dietary intake and physical activity could predict hand grip strength when controlling for ethnicity, place of residency and BMI.

Patient and public involvement

Information sheet and consent forms were given to the students and their parents/guardian prior to the recruitment. Participation into the study was based on a voluntarily basis. Feasibility study was done prior to the actual study and the findings had assisted in the flow of the actual study and data collection. Each participant was given a record book whereby the relevant results such as weight, height and hand grip strength were recorded.

RESULTS

Descriptive analysis

Of the 1012 participants, 395 were male and 617 were female. The study population was predominantly Malay (78.6%) followed by Indian (8.8%), Chinese (7.2%) and others (5.5%). At this stage of the MyHeART study, the majority of the participants had reached puberty (data not shown). The majority of the participants were right-hand dominant (90%) and the remainder were left-hand dominant (data not shown).

Table 1 provides the characteristics of the participants. It can be seen that males had significantly higher values than females in terms of weight, physical activity score, hand grip strength of both hands, energy, protein and carbohydrate intake per day, but not percentage body fat and BMI ($p<0.05$). Among the females, about two thirds (69.2%) had a low physical activity score, whereas almost two thirds of the males (65.2%) had a moderate to high physical activity score.

Correlation and regression

Table 2 shows that a positive linear relationship was found between energy, carbohydrate, and fat intakes and physical activity score with hand grip strength ($p<0.001$) among males. This result is statistically significant. However, no such correlation was found for females.

To investigate whether dietary intake and physical activity could predict hand grip strength, a linear regression was computed when controlling for ethnicity, place of residency and BMI. Before running the regressions, the assumptions of linearity, normally distributed errors and non-correlated errors were checked and met. When BMI was entered alone, it was found to significantly predict hand grip strength: $F(1, 393) = 58.09$, $p<0.001$, adjusted $R^2 = 0.127$. Only 12.7% of the variance in hand grip strength could be predicted by knowing the adolescent's BMI. When the physical activity score and energy intakes were added, the prediction improved slightly: $R^2 = 0.04$, $F(2, 391) = 9.216$, $p<0.001$. Moreover, the entire group of variables significantly predicted hand grip strength: $F(3, 391) = 26.32$, $p<0.001$, adjusted $R^2 = 0.16$ (Table 3).

Table 1: Characteristics of MyHeART participants

		Male (n=395)	Female (n=617)	All (n=1012)	*p*
Age (y)		15.04 (±0.198)	15.04 (±0.205)	15.04 (±0.202)	0.384
Ethnicity					
	Malay	307 (77.7%)	487 (78.9%)	795 (78.6%)	
	Chinese	26 (6.6%)	47 (7.6%)	73 (7.2%)	
	Indian	35 (8.9%)	54 (8.8%)	89 (8.8%)	
	Others	27 (6.8%)	29 (4.7%)	56 (5.5%)	
Place of residency					
	Urban	216 (54.7%)	367 (59.5%)	583 (57.6%)	
	Rural	179 (45.3%)	250 (40.5%)	429 (42.4%)	
Weight[a] (kg)		*51.00 (17.00)*	*48.50 (15.35)*	*49.50 (15.60)*	<0.001*
Height (cm)		163.20 (±6.76)	154.65 (±5.67)	157.99 (±7.40)	0.052
BMI[a] (kg/m2)		*18.90 (5.49)*	*20.25 (5.74)*	*19.74 (5.73)*	<0.001*
% body fat		15.50 (±11.02)	29.37 (±9.17)	23.95 (±12.01)	<0.001*
Waist circumference[a] (cm)		*67.90 (15.50)*	*69.00 (13.50)*	*68.50 (14.00)*	0.514

Differences between male and female participants were determined using an independent t-test and the Mann-Whitney test. Data are presented as means ± standard deviation or as n (%), unless otherwise stated.

**Statistically significant at a level of significance of p<0.05.*

[a]Values are expressed as medians (IQRs).

Table 1: Characteristics of MyHeART participants (cont…)

	Male (n=395)	Female (n=617)	All (n=1012)	*p*
Physical activity score	2.43 (±0.75)	2.12 (±0.54)	2.24 (±0.65)	<0.001*
Physical activity level				
low (<2.33)	177 (44.8%)	427 (69.2%)	604 (59.7%)	
moderate (2.33-3.66)	199 (50.4%)	183 (29.7%)	382 (37.7%)	
high (>3.66)	19 (4.8%)	7 (1.1%)	26 (2.6%)	
Hand grip strength (kg)				
Average hand grip strength (left) (kg)	25.95 (±7.27)	17.54 (±4.78)	20.82 (±7.16)	<0.001*
Average hand grip strength (right) (kg)	27.08 (±7.27)	18.63 (±4.59)	21.93 (±7.10)	<0.001*
Average hand grip strength (dominant hand) (kg)	27.25 (±7.16)	18.73 (±4.63)	22.06 (±7.09)	<0.001*
Energy & macronutrients intake				
Energy (kcal)	2047 (±583)	1738 (±474)	1858 (±540)	0.001*
Protein (g)	75.69 (±22.48)	66.07 (±19.45)	69.82 (±21.20)	0.04*
Carbohydrate (g)	280.71 (±90.17)	229.31 (±67.79)	249.37 (±81.23)	<0.001*

Fat (g)	68.97 (±21.74)	61.60 (±20.13)	64.48 (±21.07)	0.16

Differences between male and female participants were determined using an independent t-test and the Mann-Whitney test. Data are presented as means ± standard deviation or as n (%), unless otherwise stated.

**Statistically significant at a level of significance of p<0.05.*

[a]*Values are expressed as medians (IQRs).*

Table 2: Partial correlation (r) between dietary intake, physical activity score and hand grip strength in adolescents

	Hand grip strength for males* (n = 395)		Hand grip strength for females* (n = 617)	
	r	**P**	**r**	**p**
Energy and macronutrients intake				
Energy (kcal)	0.143	0.005**	0.012	0.770
Protein (g)	0.041	0.420	0.027	0.512
Carbohydrate (g)	0.158	0.002**	0.020	0.624
Fat (g)	0.124	0.014**	-0.007	0.859
Physical activity score	0.155	0.002**	0.037	0.358

*Controlled for ethnicity, place of residency, BMI, percentage body fat and waist circumference

***Statistically significant at a level of significance of p<0.05.*

Table 3: Multiple linear regression model for male adolescents

	Hand grip strength for male (n = 395)		
	R^2	**β**	**p**
	0.166		
Energy intake (kcal)		0.120	0.011*
Physical activity score		0.150	0.001*

*Controlled for ethnicity, place of residency and BMI

DISCUSSION

Hand grip strength, dietary intake and physical activity

Our study has shown that the muscle strength of Malaysian adolescent was much lower than their counterparts as reported by studies from Europe, United Kingdom and Columbia of South America.[11 17 38] In fact, our Malaysian female adolescents have lower muscle strength than those in Beijing, China.[39] Unfortunately, there is no large population based Asian male adolescents' data with which to compare with our results. Hence, this is the first documented muscle strength study among adolescents for both genders in Asia region. Nevertheless, this trend is similar to that reported in a study on the Malaysian adult population, which found the hand grip strength of Malaysian adults is 1.5 times lower than those in western countries.[40] Thus our finding may indicate that the muscle strength among the Malaysian population is relatively low from a young age. Indeed, the results of a longitudinal study conducted in Quebec, a province in eastern Canada, which tracked muscle strength from childhood to adulthood, suggested that low muscle strength can persist from childhood to adolescence.[41] Therefore, it is worth to have early detection of low muscle strength and build up muscle strength from a young age in which may have favourable health outcomes in later life.[1] Thus, it can be argued that low muscle strength among adolescents warrants particular attention in order to identify the root cause, and especially if there is an association with dietary intake and physical activity which are modifiable health-related behaviours.

Our results also showed that differences in hand grip strength, dietary intake and physical activity score varied between male and female adolescents. The males had higher muscle strength, consumed more energy, protein and carbohydrate and were more physically active than their female counterparts. These findings are consistent with those of previous studies conducted on study populations aged 13 years-old.[16 42 43]

Association between dietary intake, physical activity and hand grip strength

In our study, energy, carbohydrate, and fat intakes and physical activity score were positively correlated with hand grip strength for males. However, protein was not found to be correlated with hand grip strength. This result is similar to that reported by Gracia-Marco et al. whereby the researchers used the German Food Code and Nutrition Data Base, which have the breakdown of amino acids profile in order to quantify the intake of amino acids.[17] The study showed that

tryptophan, histidine and methionine (amino acids) are positively correlated with lower limb muscular strength, however, these relationships disappeared when carbohydrate intakes is controlled for.[17] According to the study, specific macronutrients such as carbohydrate play a much more important role than protein or physical activity in muscle strength. One possible explanation for this is that higher carbohydrate intake increases intravenous infusion of insulin, which results in hyperinsulinemia, which, in turn, enhances the rate of muscle protein synthesis.[44]

In addition, studies have also reported that energy plays as a moderating role in muscle strength.[22 23] Although a study that used milk supplementation and resistance training as an intervention did not improve muscle mass, the researchers argued that energy plays a mediator role in the relationship between muscle mass, protein intake and resistance training despite the finding showing otherwise.[22] Therefore, a sufficient intake of energy and/or carbohydrate to meet the daily requirement needs is required before protein can play a role in promoting muscle building and strength.

When the energy intake per day and physical activity score were put into the model while controlling for BMI, both predictors remained significantly associated with hand grip strength. We found that higher energy intake and higher physical activity score predicted higher hand grip strength. We also found that higher BMI predicted higher hand grip strength. The latter finding is consistent with that reported by a study on Southern Brazil adolescents, which found that the higher the BMI the greater the muscle strength.[21] The researchers stated that their study population had a higher body mass, particularly muscle. As our study did not include an objective measure for muscle mass, we considered body fat percentage and found that the male participants had a lower body fat percentage than the female. In addition, the average BMI of the male participants was below the overweight level using International Obesity Task Foce (IOTF) reference. Nevertheless, BMI is not generally seen as a good indicator of body composition.[45] On the other hand, there is a general consensus that the higher the body fat, especially abdominal fat, the lower the hand grip strength.[5] This could be due to fat playing an inert role in muscle strength.[46] In contrast to the above-mentioned studies, a study conducted in Italy on a sample of 2411 adolescents produced a neutral result, which suggested that obesity does not affect muscle strength among healthy schoolchildren.[47] Nonetheless, our predictive equation needs to be interpreted cautiously as it only explains about 16.6% variations in muscle strength are explained by energy intake and physical activity.

In our study, no relationship was found between dietary intake, physical activity score and hand grip strength among female adolescents. Again, this result is similar to that reported by Gracia-Marco et al..[17] The study showed that proline (amino acids) is positively correlated with lower limb muscular strength, however, these relationships disappeared when carbohydrate intakes is controlled for.[17] On the other hand, a study conducted among Kenya adolescents suggested that female adolescents have greater muscle strength than their male counterparts because the females

undertake more house chores such as transferring water from deep wells and preparing meals, thus, have greater access to food than the males.[48] All these activities eventually help to build upper limb muscle strength. However, these conditions are not commonly found in Malaysia where most adolescents are school attendees. We would postulate that the reason for our finding that female adolescents have lower muscle strength than males is because almost 70% of the females had a low physical activity score due to a predominantly sedentary lifestyle as compared to males 65% of whom had a moderate to high physical activity score. It has also been found by a previous study that females already have a lower physical activity score at an earlier age compared to males[42] and that this continues as they age.

Another possible reason for the significant result observed in males but not females could be due to changes with puberty stage, where the hand grip strength of males increases tremendously as compared to females. A study has reported that at 13 years old, the hand grip strength of males and females is 17.8 kg and 14.7 kg, respectively[16]. Muscle hypertrophy is commonly found in pre-adolescent males compared with females at the same growth stage because of increasing levels of circulating androgens.[49] Moreover, it has also been found that muscle strength increases when a male reaches puberty, which it has been argued is related to the growth spurt due to the direct action of testosterone, which has a direct anabolic effect on muscle fibers.[50] In our study population, the majority of the males had reached the puberty stage. Thus, in addition to the males being moderately to highly physically active, the presence of testosterone could explain the marked difference in muscle strength between the male and female participants.

Although the role of protein in muscle strength was not statistically significant in our study, it is still crucial to explore the effect of dietary protein as it is known to play a role in ensuring appropriate growth during adolescence.[17] Furthermore, muscle building only occurs when a person is physically active because such activity triggers the digestion and better absorption of amino acids,[51 52] which eventually increases muscle strength. Moreover, it is crucial to ensure that energy and carbohydrate intake requirements are met before protein can even play a role in improving muscle strength. The above findings therefore indicate that there is a strong need to undertake a longitudinal study to explore whether changes in dietary intake have an impact on hand grip strength among adolescents, and that takes into account the variables of physical activity and weight status.

Strengths and limitations

This study has a number of strengths. Firstly, it was conducted using a large sample of adolescents. Secondly, it used objective measurements with standard protocols for hand grip strength, dietary intake and physical activity, which ensured minimal measurement bias. Moreover, to the best of our knowledge, this study may be the first to investigate the association between hand grip strength, dietary intake and physical activity among adolescents in Asia.

However, it should be noted that this study is somewhat limited because it was cross-sectional in design, so the presence or otherwise of a causal relationship could not be established. In addition, the sample covered a narrow age range.

CONCLUSION

Our findings suggest that muscle strength is associated with energy intake and physical activity among males. However, this relationship was not found in females. This difference requires further investigation in order to gain a better understanding of the issues affecting muscle strength so as to improve the provision of nutritional and physical activity strategies for the adolescent muscular health of both genders.

ABBREVIATIONS

BMI Body Mass Index

IQR Interquartile range

Acknowledgments: The authors would like to thank Associate Professor Dr. Mohd Nahar Azmi Mohamed and Dr. 'Abqariyah Binti Yahya for the support and guidance.

Contributors: AK Ng, HA Majid and NN Hairi carried out the data analysis. AK Ng drafted the manuscript. HA Majid and MY Jalaludin contributed in the design of the study and data collection. All authors contributed to the final manuscript write up.

Funding: This study was supported by funding received from the University Malaya's Research Programme (UMRP022A-14HTM) and Postgraduate Research Fund (PG026-2016A).

Competing interests: None.

Ethical approval: Ethics Committee of the University Malaya Medical Centre (MEC Ref. No. 896.34).

Data sharing statement: No additional data are available.

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Hazreen et al. BMC Public Health 2014, 14(Suppl 3):S6
http://www.biomedcentral.com/1471-2458/14/S3/S6

BMC Public Health

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An exploratory study on risk factors for chronic non-communicable diseases among adolescents in Malaysia: overview of the Malaysian Health and Adolescents Longitudinal Research Team study (The MyHeART study)

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From International Research Symposium on Population Health 2013
Kuala Lumpur, Malaysia. 18-22 November 2013

Abstract

Background: The National Health & Morbidity Survey (NHMS) IV (2011) observed that the prevalence of obese children aged less than 18 years in Malaysia is 6.1% compared to 5.4% overweight and obese in NHMS III (2006). As such, this observation is of public health importance as obesity is a forewarning risk factor for chronic diseases such as type-2 diabetes, cardiovascular diseases (CVD) and certain types of cancers. This MyHeART (Malaysian Health and Adolescents longitudinal Research Team) study aims to examine risk factors of non-communicable diseases (NCD) among adolescents.

Methods/design: The MyHeART study is longitudinal cohort study of 1361 schoolchildren (13-years old) attending 15 public secondary schools from the central (Kuala Lumpur and Selangor) and northern (Perak) regions of Peninsular Malaysia. The study used a stratified sampling design to select the study participants. Data collected at baseline included socio-economic, lifestyle (e.g. smoking, physical activity assessment, fitness assessment, seven-day diet history), and environmental information, anthropometric measurements, blood pressure, handgrip strength and bone mineral density. Blood samples for fasting blood glucose and lipid profiles, full blood count, renal profile, as well as bone profile and serum vitamin D were taken. This study cohort will be followed up again when participants turn 15, 17 and lastly, after a period of ten years (around the age of 27).

Results: Nine percent of the adolescents from this study were obese. More male participants smoked compared to female participants (15.4% vs. 4.7%). Adolescent males had higher fasting blood glucose but the female participants had lower high density lipoprotein (HDL-cholesterol) and higher low density lipoprotein (LDL-cholesterol). In addition, adolescents from the rural area had higher fasting blood glucose, diastolic blood pressure, total cholesterol and LDL-cholesterol.

Discussion: Our results demonstrated that adolescents from the rural area are at higher risk of NCDs compared to their urban counterpart. Tailor made public health interventions are highly recommended for adolescents as this may minimise the dreadful NCD burden in adulthood and health disparity between the rural and urban in the near future.

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Background

Data from the World Health Organization (WHO) shows that non-communicable diseases (NCDs) caused approximately 63% of all deaths worldwide in 2008 [1] and almost 80% of deaths in 2008 from NCDs occurred in the low- and middle-income countries. Driven by the population growth and population ageing, deaths from the NCDs are projected to increase by 15% globally between 2010 and 2020, and will account for approximately 70% of global deaths by 2030 [1-3]. It is estimated that NCDs account for 67% of all deaths in Malaysia and there has been an increasing trend in recent decades [1,2]. Non-communicable diseases are largely attributed to modifiable and non-modifiable risk factors. The Malaysian National Health and Morbidity Survey (NHMS) 2011, demonstrated that the prevalence of obesity in less than 18 years old was 6.1% (CI: 5.6-6.8), with the highest prevalence among the Malay and Indian ethnic groups. A cross sectional study has identified unhealthy dietary intake and lack of physical activity level associated with higher body mass index among the Malaysian adolescents [4]. Behavioural risk factors such as unhealthy diet, insufficient physical activity, tobacco use, and excessive alcohol consumption, contribute to the development of various metabolic diseases such as hypertension, diabetes, hypercholesterolaemia, overweight and obesity. Alarmingly, these risk factors are also becoming rampant in adolescents and consequently, contribute to a higher cost to manage and treat NCDs in the future [3,5].

Despite various campaigns and programs undertaken to reduce the prevalence of risk factors of NCDs, these risk factors continue to be a major issue in both developed and developing countries in Asia [1]. The adolescent period encompasses several transitions whereby the family, environment and societal influences are strongly associated with their health outcomes. In an attempt to address setbacks such as lack of data and poor understanding of NCDs and its risk factors in early life among the unique, multi-ethnic Malaysian population; the MyHeART study was developed as a cohort study targeting the rural and urban adolescent communities in Malaysia. The research goals include (a) identifying the prevalence and trends, of non-communicable diseases risk factors among adolescents in Peninsular Malaysia and (b) to evaluate how lifestyle factors (e.g. dietary intake and pattern, physical activities, smoking and alcohol consumption) of early adolescents influence the development of chronic NCD in their early adulthood. To the best of our knowledge, this is the first Malaysian adolescent cohort study with a representative sample size, comparable to adolescent cohort in high-income countries [7,8].

The objective of this study is to enable early detection and possible prevention of diseases by identifying predictors of NCDs. The outcome from this study will assist in the development of future pragmatic public health interventions to prevent NCDs in settings where resources are limited.

Methods

Study area and population

This prospective cohort study was designed to recruit 1500 secondary school students from the three states in the central and northern region of Peninsular Malaysia, namely Selangor, Federal Territory of Kuala Lumpur and Perak (Figure 1). Notably, Selangor is one of the most developed and populous states in Malaysia followed by Perak. The Federal Territory of Kuala Lumpur (KL), directly governed by the federal government of Malaysia comes in third rank in regards to population although its capital city is located within this territory.

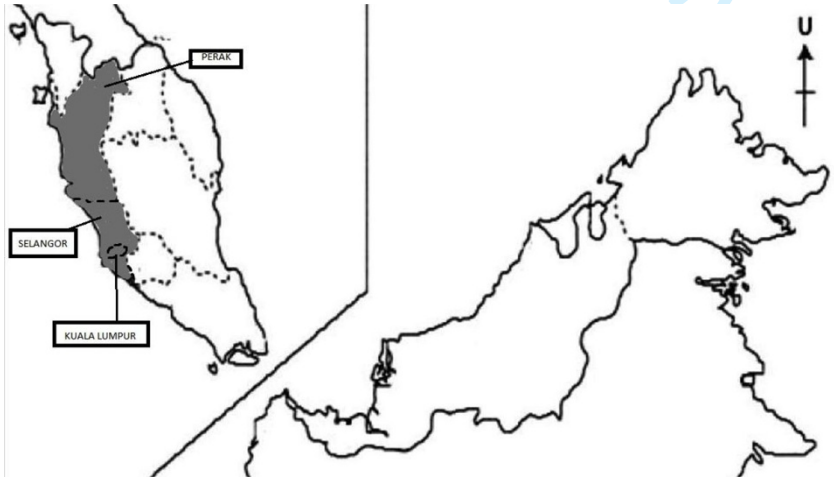

Figure 1 Map of Malaysia highlighting the study area.

Interestingly, the Federal Territory of KL is a complete urban area, whereby the central zone is largely urban with several rural areas within the northern region.

The study population were 13 years old school children from public schools, i.e. in their first year (Form 1) of secondary school. Participants were required to be able to read Malay, the national language of Malaysia. Boarding, religious and vernacular schools were excluded, as majority of its students may encompass a single ethnic group.

Sampling

The study followed a stratified sampling design. First, a complete list of the public secondary schools, located in the selected regions were obtained from the Ministry of Education Malaysia and used as the sampling frame. The schools were stratified into urban and rural based on the criteria provided by the Department of Statistics Malaysia. A number of schools from the urban and rural locations were randomly selected using computer-generated random number lists. All form one students (13 years old) who were able to speak and write in the national language were invited to participate in this study. Next, the participants and their parents/guardians received detailed written information about the study and consent forms. Finally, participants and their parents/guardians were required to submit completed consent forms to indicate their willingness to participate.

Sample size calculation

The study used the stratified sampling where the following formula was applied for sample size calculation; n = ($z^2 \times p \times q / r \times e^2$) × design effect (z = the standard normal deviate set at 1.96 at 5% level for two-tailed test, p = estimated prevalence, q = 1 - p, r = response rate and e = precision level). The sample size was calculated using the estimated prevalence of adolescent students aged 13-15 who smoked in school; 33% [7]. The total sample estimated was about 1500 participants.

Data collection

Student and parental questionnaires

Two self-administered questionnaires were used (Table 1), a Parental Questionnaire and a Student Questionnaire. These questionnaires were adapted from the Young Hearts study, an adolescent cohort study conducted in Northern Ireland [9]. The parental questionnaire gathered information on the student's birth, health and lifestyle as a child, the parents' socioeconomic status and lifestyle, as well as personal and family history of NCDs. The student questionnaire on the other hand, collected information on demographics, lifestyle, pubertal staging, sleeping practices, satisfaction with life and behavioural factors. Detailed information was collected on smoking, alcohol consumption, online and electronic usage, as well as basic information on drug intakes and gambling. Health related information including breathing/airway and skin problems was also gathered. The Tanner Staging was referred in regards to the compilation of information on pubertal development [10]. Knowledge and awareness of sexual and reproductive health issues were also assessed.

Table 1 Information gathered in the MyHEART study questionnaires.

Parental questionnaire	Data
Questions relating to the child's mother	Age, height, weight, current job, highest education, health problems during pregnancy/delivery, mode of delivery, age when delivered participant, number of children, smoking history including during pregnancy, consumption of alcoholic drinks, illnesses (obesity, high blood pressure, cholesterol, angina, heart attack, stroke, diabetes, asthma, bronchitis, osteoporosis, cancer), illness of close family members, income
Questions relating to the child's father	Age, height, weight, current job, highest education, smoking history, consumption of alcoholic drinks, illnesses (obesity, high blood pressure, cholesterol, angina, heart attack, stroke, diabetes, asthma, bronchitis, osteoporosis, cancer), illness of close family members, income
Questions relating to the child	Birth weight, gestational age, infant feeding history, history of abnormal large appetite, excess weight gain, medical conditions or disabilities (congenital defects, cardiovascular problems, diabetes, asthma, allergies, mental health etc.), medication and supplement use
Student Questionnaire	
Demographic and student's characteristics	Name, identification card number, home address, district, postcode, state, home telephone, mobile number, email, date of birth, ethnicity, religion, gender, nationality
Lifestyle	Physical activity questionnaire (PAQ-c)[15], sleep duration and quality, satisfaction with life
Health background	Eating habits, purging, dieting, breathing problems (wheezing, asthma, treatments), usage of inhalers, nose problems unrelated to flu (eg: sneezing, blocked nose), skin problems (rash, eczema)
High risk behaviour	Smoking habits, alcohol consumption, drugs intake, online and electronic usage, gambling habits
Female sexual and reproductive health	Tanner staging system, menstrual periods, knowledge on sex
Male sexual and reproductive health	Tanner staging system, knowledge on sex

In addition, these questionnaires were translated into Bahasa Melayu (the national language). Face and content validity were also evaluated in 30 subjects prior to the commencement of study. Self-administered parental questionnaires were completed by parents at home and submitted. Some missing information in the parental questionnaire was obtained with active follow-up, conducted via telephone interview, when required. The adolescents on the other hand completed their questionnaires at school (on the study day) under the supervision of the research team who ensured no required particulars were missing.

Dietary assessment

Generally, habitual dietary intake can be assessed using several methods such as diet histories (24-hour dietary recall or seven-days), food frequency, three days dietary records and duplicate food weighing to evaluate energy intake. However, the seven-days diet history was chosen for this study as this method has produced more valid estimates of energy intake in children and adolescents compared to other methods [11,12]. The tool was pretested on 40 participants from two different schools (one school each from urban and rural area respectively). For the actual study, seven qualified and trained dietitians used open-ended interviews with the students to collect information on the food and drinks that they consumed for breakfast, mid-morning snacks, lunch, afternoon tea, dinner and supper over the previous seven day period. Illustrated flip charts containing local food were used as supplementary tools to assist the study participants during the dietary evaluation and to help estimate the portion size of the foods that they consumed [13]. Nutrient intake was calculated using the Nutritionist Pro™ Diet Analysis (Axxya Systems, US) software.

Physical activity

Self-reported physical activity was assessed using validated physical activity questionnaire for older children (PAQ-C) based on a Malay version, which has good internal consistency and acceptable validity [14,15]. Ten items were assessed in PAQ-C to obtain physical activity level of the adolescents in the past seven days. The first item included the type and frequency of sports or/and dance the adolescents performed during the past seven days. The second to eighth items of the questionnaire assessed the activity of the adolescents during physical education (PE) classes, recess, lunch time, right after school, evenings, weekend and leisure periods. Five point Likert scale was used to answer items two to four. Item nine included the previous week physical activity frequency and item ten to report any unusual activities during the previous week. The categorisation of PAQ-C was based on a study by Crocker *et al.* [16].

Physical evaluation

Height was measured without socks and shoes using a calibrated vertical steadiometer (Seca Portable 217, Seca, UK), and was recorded to the nearest 0.1 cm. Weight was measured with light clothing, using a digital electronic weighing scale (Seca 813, Seca, UK) and was recorded to the nearest decimal fraction of kilogram (0.1 kg). Body mass index (BMI) was calculated as weight in kilograms divided by the square of height in meters. Body mass index z-score for age and gender was calculated using the World Health Organization (WHO) Anthro Software version 3.2.2 for the Statistical Package for the Social Sciences (SPSS) macro, based on WHO reference 2007 (WHO, Geneva, Switzerland). Body fat composition was measured using a portable body composition analyser (Tanita SC-240 MA, Body Composition Analyser, Tanita Europe B.V., The Netherlands). Both waist circumference (WC) and hip circumference (HC) were respectively measured with a non-elastic Seca measuring tape (Seca 201, Seca, UK), to the nearest millimetre.

A calibrated hand dynamometer (Jamar, Sammons Preston Rolyan, Illinois, US) was used to perform the hand grip strength test. Participants were asked to show their dominant hand. The first test was performed with dominant hand and next, with the non-dominant hand. Three sets of test were repeated alternately for both hands. The length of the hand span was also measured from the tip of the thumb to the tip of the small finger with the hand opened as wide as possible using a non-elastic Seca measuring tape (Seca 201, Seca, UK), to the nearest millimetre. Bone mineral density was measured using a portable broadband ultrasound bone densitometer (Hologic Sahara, Hologic Inc., USA).

Medically trained personnel, paediatricians, medical officers or staff nurses, measured the blood pressure and pulse rate of the participants after an interval of five minutes between each reading. The participants sat upright with his or her right upper arm positioned at the level of the heart with both feet flat on the floor. Systolic and diastolic arterial blood pressure were obtained using a stethoscope and a mercury sphygmomanometer (CK-101C, Spirit Medical Co.,Taiwan). Three readings of blood pressure were taken with two minutes interval between each reading and the mean of the three readings were obtained.

Exercise test

An exercise test was performed under the close supervision of a sports physician. Participants with known medical conditions, musculoskeletal injuries, or who were acutely ill were excluded. The modified Harvard Step Test protocol (30 cm step) was used as it objectively categorises the performance level of children [17]. The participants get onto and off the step box at a pace of 30 cycles per

Hazreen et al. BMC Public Health 2014, 14(Suppl 3):S6
http://www.biomedcentral.com/1471-2458/14/S3/S6

minute with a metronome set at 120 beat per minute (bpm), for a total of five minutes. A finger pulse oximeter (Baseline 12-1926 Fingertip Pulse Oximeter, Fabrication Enterprises Inc., USA) was attached to one of the student's fingers, and the pulse rate was then continuously monitored. The peak pulse rate of each student during each minute of the step box exercise was recorded. Those with a pulse rate of 200 bpm, and those who had difficulty in breathing, or were unable to finish, were directed to stop immediately.

Blood profile

Participants were asked to fast for at least ten hours before the study. A total of 15 ml of fasting blood was withdrawn from each participant at baseline and subsequently collected during the follow up cohort. Blood were sent to the certified International Organization for Standardization (ISO) hospital pathology lab for analysis. The samples were temporarily stored at four degrees Celsius in a cool box immediately after the blood had been withdrawn to preserve levels of markers that are sensitive to degradation due to increase in temperatures. All samples were processed in the field laboratories in the states. Samples were spinned and stored as serum and divided into several aliquots of 0.5 ml of serum. The following tests were performed at the field laboratories: full blood count (Advia 2120 flow cytometry, Siemens, Germany), fasting blood glucose (Advia Chemistry, Siemens, Germany), renal, lipid and bone profiles (Advia Chemistry, Siemens, Germany), vitamin D and parathyroid hormone (Advia Centaur XP immunoassay, Siemens, Germany). All the aliquots for future lab analysis were stored at a temperature of 80 degree Celsius freezers at the field laboratories until they were ready to be transported back to the University of Malaya (UM) bio bank.

Additional blood sampling (three ml bloods for serum and preparation of buffy coats) will be collected in future cohorts to control errors that may arise from single sampling. All other blood measurements in this cohort will be repeated in the future cohorts.

Proposed follow-up and outcome measurement

The cohort will be followed up at two, four and 14 years post baseline data collection. Similar assessments will be performed including the questionnaires, seven-days diet recall, anthropometric measurement, blood pressure measurement, exercise test and blood sampling. In Malaysia, each citizen is provided with a national identification (ID) card that has a unique number sequence. This identification number will be used during follow-up to ensure correct matching of longitudinal data of each individual.

Dissemination of results to the participants

Results on full blood counts, renal profile, fasting blood glucose and lipid profile were verified by a paediatrician and disseminated to the participants' parents. The participants were informed to have a clinic follow-up at the nearest government clinics or at our institution for further management or treatment if the results were beyond the clinical reference ranges and if they require urgent medical attention.

Data management and data access

Data entry of questionnaires and blood results were entered manually. The principal researchers had prepared the template for data entry. However, to minimise errors from manual data entry, two trained researchers cross-checked data entered by each other. Regular checking and data cleaning were implemented. Any discrepancies were notified to the data manager.

To ensure standardised data management, training was provided to field researchers who are involved in the data collection. Next, all questionnaires were checked by the field researchers for its completeness. Data are treated confidentially by removing any identification (names, addresses and national identification number) and specific ID was provided for data analysis. These confidential data are only accessible to the authorised research members. All the data are stored on the University of Malaya server. Requests for any data or information for the purpose of writing a manuscript can be made to the authorised research staff via email.

Definitions

Overweight and obesity was defined using the International Obesity Task Force criteria with extrapolation to adult BMI cut-offs of 25 kg/m^2 for overweight (21.91 kg/m^2 for males and 22.58 kg/m^2 for female) and 30 kg/m^2 for obesity (26.84 kg/m^2 for male and 27.76 kg/m^2 for female) [18]. The cut-off value used for waist circumference at 90^{th} percentile was 83.8 cm for male and 78.8 cm for female [19]. The cut-off points for at risk of metabolic syndrome includes high density lipoprotein (HDL)-cholesterol <1.03 mmol/l, triglycerides ≥1.7 mmol/l and fasting plasma glucose ≥5.6 mmol/l or known type 2 diabetes mellitus [20]. Blood pressure is considered high if the systolic blood pressure ≥130 mmHg or diastolic blood pressure ≥85 mmHg [20].

Data analysis and statistical methods

For data analysis, the SPSS software for Windows (Version 20.0, Chicago, IL, US) was used. Qualitative variables were described as frequencies and percentages.

For baseline comparison, the chi-square tests were used to compare groups. To compare two groups for quantitative variable, the *t*-test was used if variances are equal and non-parametric Mann-Whitney-U test were used, otherwise.

For comparing more than two groups, the ANOVA procedure was used, and where necessary, the non-

parametric Kruskal-Wallis test was used. Multiple linear regressions were performed separately by gender to determine the relationship between body composition measurements and selected variables.

In analysing longitudinal data, repeated measures and generalised estimation procedures in SPSS will be used. Attempt will be made to analyse the data using latent growth models in the AMOS software.

Ethical considerations

Ethical approval was obtained from the Medical Ethics Committee, University Malaya Medical Centre (MEC Ref. No: 896.34). The National Medical Research Register number is 14-376-20486. Participation in the study was voluntary and written informed consent and ascent for participation in the study was obtained from the parents or guardian as well as the participants.

Results

In total, at the time of sampling, there were 238 secondary schools in the northern zone, 261 in the central zone and 96 in KL. Based on a feasibility study performed in 2011, and an estimate of recruitment of approximately 80-120 students per school, 15 schools were randomly selected for the study, five in Selangor, seven in Perak and three in KL; eight were urban schools and seven rural. There were 2694 eligible participants within the schools and 1361 voluntarily participated between March and May 2012, giving an overall response rate of 51%. Urban schools response rate ranges from 22%-53% whilst rural schools response rates range from 40%-84%.

The distribution of the participants in terms of gender, ethnicity and location (urban and rural) and key risk factors for chronic non-communicable diseases including hypertension, fasting blood glucose, hypercholesterolaemia, overweight/obesity and smoking are shown in Table 2.

Table 2 shows the breakdown of the participants in terms of age, sex, ethnicity, location (urban or rural) and the prevalence of cardiovascular risk factors. There were more female participants than male participants and higher number of participant were from the urban schools compared to rural. There were more Malay compared to the other two ethnic groups as Malay is the major ethnic group in Malaysia. The overall prevalence of reported smoking was 8.8%, out of which 15.4% represented male participants and 4.7% represented females participants. The overall overweight/obese prevalence among the adolescents in this study was 23.9%, with 8.5% of them obese and 15.4% overweight.

Discussion

The baseline data collected in the MyHeART study showed the prevalence of overweight in Malaysian adolescents was around 15% for both males and females with the prevalence of obesity in males recorded higher percentage than the females (10.7% vs. 7.2%). Furthermore, our studies have shown an increasing trend of overweight children aged 1-12 years from 20.7% in 2002 to 26.5% in 2008 within the Peninsular Malaysia (National Strategic Plan 2010) and a higher prevalence of 34.2% was reported for the prevalence of overweight and obese children in metropolitan Kuala Lumpur [21]. The prevalence of overweight and obese Malaysian adolescents is also higher than other South East Asian countries such as the Philippines' (4.8%) [22] and Thailand (16.6%) [23]. Hence, this is certainly alarming as the trend of overweight and obesity for developing country like Malaysia is mirroring countries like England i.e., following an increasing trend where 11% of male and 12% of female aged 2 until 15 years were obese [24]. In addition, the prevalence of overweight or obese adolescents in the United States for those aged 12 to 19 years was also high, 35% compared to 4.6 % in 1963 [25].

Evidences of childhood obesity leading to complications related to obesity in adulthood [25,26] remain consistent and urbanisation may contribute to the rise of overweight and obese population in Malaysia. Although the worldwide study (n = 19244) revealed that adult obesity in developed countries have slowed down, the prevalence of obesity among adults in developing countries is still disturbing, exceeding 50% [27]. The influence of urbanisation as a result of high economic growth has undoubtedly contributed to the prevalence of overweight and obese adolescents in China [28], India [29], Argentina [30] and Poland [31]. Similarly, the rapid economic growth and urbanisation may have played a crucial role in the increased prevalence of overweight and obesity in Malaysia.

The prevalence of cardiovascular risk factors (high fasting blood glucose and smoking) was found to be higher in male participants compared to female participants. However, female participants were noted to have lower HDL-cholesterol (a protective cardiovascular risk factor). Adolescents from the rural areas were found to have higher fasting blood glucose, diastolic blood pressure, total cholesterol and low-density lipoprotein (LDL)-cholesterol levels compared to their urban counterpart. Hence, it is vital to monitor and screen these adolescents especially those in rural areas since these markers of metabolic syndrome are strongly associated with early cardiac disease and type-2 diabetes mellitus [32-34].

On a positive note, there are several strengths that can be highlighted from this study. To our knowledge, this is the first adolescent cohort study to be conducted in Malaysia that has a comprehensive anthropometric assessment, complete fasting blood profile and dietary assessment. At present, there is one large adult cohort similar to this study that was conducted in Malaysia i.e. The Malaysian Cohort [35]. As such, our study may

Hazreen *et al. BMC Public Health* 2014, **14**(Suppl 3):S6
http://www.biomedcentral.com/1471-2458/14/S3/S6

Table 2 Demographic Characteristics and prevalence of parameters for adolescent aged 13 years old by gender and Place of Residences

Baseline characteristic (N = 1361)	Male N = 525 No (%)	Female N = 836 No (%)	Total (%)	Chi square x^2	Chi square p-value
Place of residence					
Urban	240 (45.7)	483 (57.8)	723 (53.1)	18.8	<0.001
Rural	285 (54.3)	353 (42.2)	638 (46.9)		
Systolic Blood Pressure (mmHg)					
Normal (<130)	497 (95.2)	795 (95.1)	1292 (94.9)		
Hypertensive (≥130)	25 (4.8)	33 (3.9)	58 (4.3)	0.5	0.478
Diastolic Blood Pressure (mmHg)					
Normal (<85)	496(94.5)	788 (94.3)	1284 (94.3)		
Hypertensive (≥85)	26 (5.0)	40 (4.8)	66 (4.8)	0.02	0.901
Fasting Blood Glucose (mmol/L)					
Normal (3.9-5.5)	496 (94.5)	788 (94.3)	1284 (94.1)	9.3	<0.05
High (≥5.6)	26 (5.0)	27 (3.2)	53 (3.9)		
Low (<3.9)	3 (0.6)	21 (2.5)	24 (1.8)		
Total Cholesterol (mmol/L)					
Desirable (<5.2)	415 (79.0)	624 (74.6)	1039 (76.3)	3.5	0.176
Borderline (5.2-6.2)	92 (17.5)	178 (21.3)	270 (19.8)		
High Risk (>6.2)	18 (3.4)	34 (4.1)	52 (3.8)		
HDL Cholesterol (mmol/L)					
At risk (≤1.03)	478 (91.0)	795 (95.1)	1273 (93.5)	8.74	<0.05
Normal (>1.03)	47 (9.0)	41 (4.9)	88 (6.5)		
LDL Cholesterol (mmol/L)					
Optimal (<2.58)	252 (48.0)	334 (40.0)	586 (43.1)		
Near Optimal (2.58-3.34)	179 (34.1)	343 (41.0)	522 (38.4)		
Borderline (3.35-4.11)	73 (13.9)	120 (14.4)	193 (14.2)	9.74	<0.05
High (4.12-4.89)	15 (2.9)	31 (3.7)	46 (3.4)		
Very high (>4.9)	6 (1.1)	8 (1.0)	14 (1.0)		
Triglycerides (mmol/L)					
Normal (<1.7)	491 (93.5)	784 (93.8)	1275 (93.7)	0.04	0.850
High (≥ 1.7)	34 (6.5)	52 (6.2)	86 (6.3)		
BMI (IOTF standards kgm^{-2})					
Underweight (<15.8^{m}; <16.3^{f})	103 (20.0)	183 (23.0)	286 (21.9)		
Normal (15.8 - <21.9^{m}; 16.3 - <22.6^{f})	282 (53.7)	456 (54.5)	738 (54.2)	5.8	0.329
Overweight (<21.9 - <26.8^{m}; 22.6 - <27.8^{f})	82 (15.6)	128 (15.3)	210 (15.4)		
Obese (≥26.8^{m}; ≥27.8^{f})	56(10.7)	60 (7.2)	116 (8.5)		
Smoking					
No	432 (82.3)	790 (94.5)	1222 (89.8)	47.8	<0.001
Yes	81 (15.4)	39 (4.7)	120 (8.8)		
	Urban No (%)	**Rural No (%)**	**Total (%)**	**Chi square x^2**	**Chi square p-value**
Ethnicity					
Malay	521 (72.1)	570 (89.3)	1091 (80.2)		
Chinese	98 (13.6)	7 (1.1)	105 (7.7)	118.5	<0.001
Indian	83 (11.5)	22 (3.4)	105 (7.7)		
Others	12 (1.7)	29 (4.5)	41 (3.0)		
Systolic Blood Pressure (mmHg)					
Normal (<130)	680 (94.1)	612 (95.9)	1292 (94.9)		
Hypertensive (≥130)	32 (4.4)	26 (4.1)	58 (4.3)	0.14	0.705

Table 2 Demographic Characteristics and prevalence of parameters for adolescent aged 13 years old by gender and Place of Residences *(Continued)*

Diastolic Blood Pressure (mmHg)					
Normal (<85)	687 (95.0)	597 (93.6)	1284 (94.3)		
Hypertensive (≥85)	25 (3.5)	41 (6.4)	66 (4.8)	6.1	<0.05
Fasting Blood Glucose (mmol/L)					
Normal (3.9-5.5)	692 (95.7)	592 (92.8)	1284 (94.1)	10.7	<0.05
High **(≥5.6)**	26 (3.6)	27 (4.2)	53 (3.9)		
Low (<3.9)	5 (0.7)	19 (3.0)	24 (1.8)		
Total Cholesterol (mmol/L)					
Desirable (<5.2)	579 (80.1)	460 (72.1)	1039 (76.3)		
Borderline (5.2-6.2)	127 (17.6)	143 (22.4)	270 (19.8)	15.6	<0.001
High Risk (>6.2)	17 (2.4)	35 (5.5)	52 (3.8)		
HDL Cholesterol (mmol/L)					
At risk (≤1.03)	681 (94.2)	592 (92.8)	1273 (93.5)	1.1	0.294
Normal (>1.03)	42 (5.8)	46 (7.2)	88 (6.5)		
LDL Cholesterol (mmol/L)					
Optimal (<2.58)	343 (47.4)	243 (38.1)	586 (43.1)		
Near Optimal (2.58-3.34)	271 (37.5)	251 (39.3)	522 (38.4)	27.9	<0.001
Borderline (3.35-4.11)	93 (12.9)	100 (15.7)	193 (14.2)		
High (4.12-4.89)	10 (1.4)	36 (5.6)	46 (3.4)		
Very high (>4.9)	6 (0.8)	8 (1.3)	14 (1.0)		
Triglycerides (mmol/l)					
Normal (<1.7)	670 (92.7)	605 (94.8)	1275 (93.7)	2.67	0.102
High (≥ 1.7)	53 (7.3)	33 (5.2)	86 (6.3)		
Smoking					
No	656 (90.7)	566 (88.7)	1222 (89.8)	1.26	0.262
Yes	58 (8.0)	62 (9.7)	120 (8.8)		

m=male, f=female

contribute to the lack of knowledge in regards to the health status among the younger generation of Malaysians. Moreover, most studies conducted on school children in Malaysia were cross-sectional studies, as such previous analyses may not be able to capture the progression and variation of biomarkers, anthropometric measurements, nutritional status and diet among the adolescent cohort. Next, this study used stratified sampling to ensure adequate recruitment of participants from both urban and rural. As such, our study enabled us to investigate health disparity between rural and urban adolescents. Although seven-days diet history is the most reliable tool to assess energy intake for this group, its implementation requires a lot of resources and it is costly. By having a validated food frequency questionnaire (FFQ), resources can be minimised and simultaneously enable the dietary intake to be reported by the respondents independently. To date, there is only one validated FFQ for adolescents in Malaysia with subjects recruited exclusively from one state and were predominantly Malays [36]. The data that we gathered from this study using the seven-days diet history on the other hand will assist us in the development of a more robust FFQ for adolescents. This new FFQ will be validated against the biomarkers.

On the contrary, despite all the advantages mentioned above, the first cohort has several limitations such as low representative of the Chinese and Indian ethnic groups. Thus for the next cohort, it is necessary to oversample the Chinese and Indian ethnic groups for further recruitment. Next, questionnaires were entered manually and therefore, for future cohorts, it would be beneficial to use software [37] that can classify paper forms and convert the required data into usable digital information, enabling researchers to extract information easily.

Results from this cohort may potentially help the stakeholders and researchers to conduct and evaluate appropriate intervention that may give an impact towards the improvement of adolescents' health status and consequently for their adulthood. This will also lead to the development of health policies that will influence the national strategic plan for better health outcome thus minimising the treatment cost of the chronic NCDs. To ensure this cohort study is a successful venture, careful considerations and appropriate strategies should be implemented. Few important considerations

to minimise the time that may affect participants study time were by conducting the recruitment systematically during physical education day and recruiting participants between February and June to ensure the recruitment period is far from the examination months. The school team involvement in planning and implementing future cohorts is important, and this is constantly being built up by building good rapport between researchers and the school team.

In conclusion, it appears that adolescents' male participants in this cohort have higher fasting blood glucose and reported smoking compared to female participants at a young age of 13 years old, with the females having lower HDL-cholesterol. This study also revealed that the adolescents from the rural area had more non-communicable diseases risk factors. The result of this study is hoped to gain the attention of the public health sector to develop more effective measures in schools to minimise this present health gap.

Competing interests
The authors declare that they have no competing interests.

Authors' contributions
All authors contribute to the study design; MAH, MYJ, NAS and TTS were involved in the field work and data collection. MAH was responsible for the drafting of this manuscript and all authors approved the final manuscript.

Acknowledgements
This study was supported by grants from University of Malaya Research Programme (RP022A-14HTM) and Vice Chancellor Research Grant (UMQUB3D-2011). The post-doctoral research fellow position for this project was jointly funded by University of Malaya and Queen's University of Belfast. The funders had no role in study design, collection, analysis and interpretation of data, writing of manuscript, or decision to submit for publication. We would like to thank all the enumerators who helped us throughout data collection. We are also grateful for the support and guidance provided by MyHeART study group members (Dr Nik Rubiah Nik Abdul Rashid and Dr Zarihah Mohd Zain (Ministry of Health, Malaysia), Dr Maizurah Omar (USM), Dr Mohamad Haniki Nik Mohamed (UIA), Dr Khadijah Shamsuddin (UKM), Dr Rosnah Sutan (UKM), Dr Sim Pei Ying (University of Malaya) and Dr Nahar Mohd Azmi (University of Malaya).
This article has been published as part of *BMC Public Health* Volume 14 Supplement 3, 2014: Proceedings of the International Research Symposium on Population Health 2013. The full contents of the supplement are available online at http://www.biomedcentral.com/bmcpublichealth/supplements/14/S3. Publication charges for this supplement were funded by the University of Malaya.

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Published: 24 November 2014

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doi:10.1186/1471-2458-14-S3-S6
Cite this article as: Hazreen *et al.*: An exploratory study on risk factors for chronic non-communicable diseases among adolescents in Malaysia: overview of the Malaysian Health and Adolescents Longitudinal Research Team study (The MyHeART study). *BMC Public Health* 2014 **14**(Suppl 3):S6.

STROBE 2007 (v4) checklist of items to be included in reports of observational studies in epidemiology*

Checklist for cohort, case-control, and cross-sectional studies (combined)

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	1
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	3
Objectives	3	State specific objectives, including any pre-specified hypotheses	3
Methods			
Study design	4	Present key elements of study design early in the paper	4
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	4
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	4
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	Not applicable
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	4-5
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	4-5
Bias	9	Describe any efforts to address potential sources of bias	Not applicable
Study size	10	Explain how the study size was arrived at	4
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	6
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	6
		(*b*) Describe any methods used to examine subgroups and interactions	6
		(*c*) Explain how missing data were addressed	Not applicable
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed	Not applicable

		Cross-sectional study—If applicable, describe analytical methods taking account of sampling strategy	
		(*e*) Describe any sensitivity analyses	Not applicable
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	6
		(b) Give reasons for non-participation at each stage	6
		(c) Consider use of a flow diagram	Not applicable
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	6, 8-9
		(b) Indicate number of participants with missing data for each variable of interest	6
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	Not applicable
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	Not applicable
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	Not applicable
		Cross-sectional study—Report numbers of outcome events or summary measures	Not applicable
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	6-7, 10
		(*b*) Report category boundaries when continuous variables were categorized	Not applicable
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	Not applicable
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	Not applicable
Discussion			
Key results	18	Summarise key results with reference to study objectives	11-13
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	13
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	13
Generalisability	21	Discuss the generalisability (external validity) of the study results	13
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	14

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

Dietary intake, physical activity and muscle strength among adolescents: the Malaysian Health and Adolescents Longitudinal Research Team (MyHeART) study

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2018-026275.R1
Article Type:	Research
Date Submitted by the Author:	15-Jan-2019
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Primary Subject Heading:	Public health
Secondary Subject Heading:	Paediatrics, Nutrition and metabolism
Keywords:	Hand grip strength, Dietary intake, Adolescents, Physical activity, muscle strength

Research article

Dietary intake, physical activity and muscle strength among adolescents: the Malaysian Health and Adolescents Longitudinal Research Team (MyHeART) study

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Word Count, excluding title page, abstract, references, figures and tables: 4000 words.

Tables: 3

Figure: 1

Funding Statement: This study was supported by funding received from the University Malaya's Research Programme (UMRP022A-14HTM) and Postgraduate Research Fund (PG026-2016A).

Funding

University of Malaya Research Grant (UMRP022A-14HTM), UMSC grant cycle 1-2016 and all the school children who participated in this study. The funding bodies did not contribute to the design of the study, data collection, analysis, or interpretation of data.

Disclosure: The authors declare that they have no conflict of interests.

Author Contributions/ Statement of authorship: AK Ng, HA Majid and NN Hairi carried out the data analysis. AK Ng drafted the manuscript. HA Majid and MY Jalaludin contributed in the design of the study and data collection. All authors contributed to the final manuscript write up.

Ethics approval and consent to participate

Ethical approval was obtained from the Medical Ethics Committee, University Malaya Medical Centre (MEC Ref. No: 896.34). The National Medical Research Register number is 14-376-20486. Participation in the study was voluntary and written informed consent and ascent for participation in the study was obtained from the parents or guardian as well as the participants.

Title: Dietary intake, physical activity and muscle strength among adolescents: the Malaysian Health and Adolescents Longitudinal Research Team (MyHeART) study

ABSTRACT

Objective: To examine the role of dietary intake and physical activity in muscle strength among adolescents.

Design: Cross-sectional analysis.

Setting: The Malaysian Health and Adolescents Longitudinal Research Team (MyHeART) study.

Participants: Fifteen-year-old secondary school children who have given consent and who participated in the MyHeART study in 2014.

Primary outcome measure: Muscle strength was measured in relation to dietary intake (energy and macronutrients) and physical activity by using a hand grip dynamometer.

Results: Among the 1012 participants (395 male; 617 female), the hand grip strength of the males was higher than that of the females (27.08 kg vs 18.63 kg; $p<0.001$). Also, males were more active (2.43 vs 2.12; $p<0.001$) and consumed a higher amount energy (2047 kcal vs 1738 kcal, $p<0.001$), carbohydrate (280.71 g vs 229.31 g; $p<0.001$) and protein (1.46g/kgBW vs 1.35g/kgBW; $p<0.168$). After controlling for ethnicity, place of residency and body mass index (BMI), there was a positive relationship between hand grip strength and the intake of energy ($r=0.14$; $p=0.006$), carbohydrate ($r=0.153$; $p=0.002$) and fat ($r=0.124$; $p=0.014$) and the physical activity score ($r=0.170$; $p=0.001$) and a negative relationship between hand grip strength and the intake of protein ($r=-0.134$; $p=0.008$), for males. However, this was not observed among females.

Conclusions: Energy, carbohydrate and fat intakes and physical activity score were positively correlated with hand grip strength while protein intake was negatively correlated with hand grip strength in males but not in females.

Keywords: Muscle strength, Hand grip strength, Dietary intake, Physical activity, Adolescents

ARTICLE SUMMARY

Article focus

- Muscle strength, as measured by hand grip strength, is an important indicator of health-related outcomes among adolescents.
- The potential effect of dietary intake on the muscle strength of adolescents is investigated.

Key messages

- After controlling for ethnicity, place of residency and body mass index, the results show that greater intake of energy, carbohydrate and fat and a higher physical activity score are associated with greater hand grip strength in males. However, this was not observed in females.
- The results also show that energy intake and physical activity score have positive effects on male hand grip strength after controlling for body mass index.

Strengths and limitations of this study

- The main strengths of this study are that it used a large sample of adolescents and the standardised measurement of muscle strength.
- This study is also the first to investigate the association between dietary intake, physical activity and muscle strength among adolescents in Asia.
- The main limitations of this study are that the sample covers a limited age range and the cross-sectional design of the study does not allow any causality interpretations.

INTRODUCTION

Recent research has paid much attention to poor muscles strength among adolescents and its association with adverse health-related outcomes, including cardiovascular disease,[1] poorer metabolic profile,[2-4] obesity[5 6] and musculoskeletal pain[7] as well as premature death from any cause.[1] Furthermore, a cross-sectional study among adolescents in a city in southern Brazil reported a prevalence of low muscle strength of 47% among the study population.[8] Moreover, most studies have suggested that there is a declining trend of muscle strength among adolescents over time[9-12] except for a study conducted in Colombia[13] that indicated otherwise. The study in Colombia, a middle-income country, also found that, adolescents have a lower hand grip strength compared to those in high-income countries.[13] Similarly, a preliminary finding from the MyHeART study showed that Malaysian adolescents have a lower handgrip strength than those in other countries.[9 14 15] However, it was not possible to categorise the hand grip strength of Malaysian adolescents based on the cutoff values used[8] as there were no available normal values for Asian adolescents. Moreover, the published cutoff values should not be used as the reference standard for Asian populations because most Asians are not able to achieve the published cutoff values.[16]

Issues pertaining to unhealthy dietary intake[17] and low physical activity[18] among adolescents are well documented worldwide,. In fact, dietary intake and/or low physical activity are increasingly recognised to be modifiable health-related behavioural determinants of muscle strength among adolescents.[15 19-21] the results reported by population-based cohort studies regarding the effect of energy and macronutrient intake are limited at this point in time.[15 22] For instance, a cross-sectional study that was conducted among European adolescents found that specific amino acids are associated with muscle strength; however, when carbohydrate is controlled for, these relationships disappear. [15] Another cohort study from India in which pregnant women and children were given a balanced protein-calorie supplementation and the children were followed up at adult stage, also emphasised the importance of an adequate energy intake in order to increase muscle strength. The cohort study also found that energy intake and physical activity are positively associated with muscle strength.[22] Furthermore, an experimental study on adolescents found that milk supplementation with resistance training does not change body composition.[23] However, the authors argued that it could be due to energy intake playing a vital role in the relationship between body composition, resistance training and the effect of these factors on both muscle mass and strength.[23]

In view of the changes that take place in the skeletal muscle in response to energy and macronutrient intake particularly carbohydrate and protein intake, in normal physiology[24], it is worthwhile to further investigate the relationship between dietary intake, particularly energy and macronutrients, and muscle strength. While previous studies have provided some evidences to demonstrate that low level of physical activity level[8 25] and being overweight[8] are associated with low hand grip strength, it seems that no studies have evaluated the influence of dietary intake and physical activity on hand grip strength among adolescents specifically. Thus, the relationship between dietary intake, physical activity and muscle strength among adolescents is not yet well understood. Moreover, to the best of the authors' knowledge, only a limited number of studies have investigated the association between hand grip strength, dietary intake and/or physical

activity among adolescents, particularly in Asia. Therefore, the purpose of this paper is to examine the association between hand grip strength, dietary intake and physical activity among adolescents in Malaysia.

METHODS

This cross-sectional study is a secondary analysis of data derived from the first follow-up of the Malaysian Health and Adolescents Longitudinal Research Team (MyHeART) study. The population for the current study was comprised of 15-year-old adolescents attending public secondary schools in the central and northern regions of Peninsular Malaysia. The sampling method used was multistage random sampling. The primary sampling units were the schools and the secondary sampling units were the students. In the first stage, the study frame was a complete list of public schools in the two above-mentioned regions from which total of 15 public secondary schools were selected. In the second stage, the defined study population was selected from a complete list of Form Three students in each of the selected school. Full details of the original MyHeART study protocol have been published elsewhere.[26]

In 2014, 1230 adolescents were recruited for the MyHeART study. Out of the total participants in 2014, 1012 (82.3%) were included in the analysis for this paper. A flowchart of the sampling procedure used to select the participants for this study is provided in Figure 1.

The MyHeART study was approved by the Ethics Committee of the University Malaya Medical Centre (MEC Ref. No. 896.34). Subsequently, formal approval was obtained from the Ministry of Health and Ministry of Education and then approval was sought from the relevant state level administrative authorities before approaching the Headmasters and Headmistresses of the selected schools.

The data collection was conducted by the MyHeART team, which was led by the principal investigator. The team consisted of 20 research assistants (medical doctors, nurses and dietitians) who collected the data at various stations such as anthropometry, hang grip strength and dietary stations. The data was collected between March and May in 2014. Prior to conducting data collection, Principle Investigator provided orientation and training sessions for the research assistants in order to familiarise them with the objectives and methodology of the study as well as hands-on practice in measuring the anthropometrics and hand grip strength. In addition, the researcher assistants who were dietitians received training on how to conduct the seven-days diet history using standardised portion of food and how to translate the diet history into a coding sheet in order to ensure the consistency and quality of the collected data.

Muscle strength

Hand grip strength has been shown to have moderate to strong validity and high reliability in tests for upper body and lower body strength in adolescents.[27] Moreover, hand grip strength has been found to be valid, reliable and feasible for school setting.[28] Therefore muscle strength was assessed by using hand grip strength. A calibrated hand dynamometer (Jamar, Sammons Preston Rolyan, Illinois, US), whose unit of measurement is the kilogram, was used in the assessment of hand grip strength. The strength of the dominant and the non-dominant hand was recorded. Prior to the measurements being taken, the dynamometer was calibrated. Then, it was adjusted for different hand sizes. The dominant and non-dominant hands of the participants were each tested three times and the readings were recorded to the nearest 0.1 kg. The average of the three readings for the dominant hand was used in analysis. All the measurements were done by trained research assistants.

Dietary intakes

Dietary intake was assessed by using a 7-day diet history. The diet history is the best method by which to estimate adolescents' intakes because they can better recall what they have eaten and drunk and this history can thus reveal more accurate information about their overall intakes.[29] This method also shows less variation in dietary assessment from the epidemiological perspective[30] and is more representative of adolescents' habitual intakes than other methods.[31 32] The seven-day diet history was collected by trained research assistants who were qualified dietitians. The *Nutrient Composition of Malaysian Food* (4th edition)[33] was used to calculate energy and macronutrient intakes and the values were entered into the Nutritionist ProTM database (Axxya Systems, USA).[33] The intakes from food items and recipes that could not be found in the *Nutrient Composition of Malaysian Food* were calculated on the basis of the details provided by the food packaging and the recipe. These calculations were then entered into the database by adjusting them based on standard recipes (per serving size). After the diet history had been analysed, 10% of the data was randomly cross-checked by an independent qualified dietitian who was not involved in analysing the dietary data. The margin of error was 4.4%. It was seemed acceptable as it has been stated that a 10% margin of error is acceptable.[34] Implausible energy intakes <500 kcal/day or >5000 kcal/day were excluded from this analysis.[35]

Physical activity score

A Malay version of the validated physical activity questionnaire for older children (PAQ-C) consisting of 10 items was used to obtain the physical activity level of the adolescents over the past 7 days. The PAC-Q questionnaire has been shown to be valid and to have good internal consistency.[36-38] The translated version has been validated in a local setting, achieving an α-Cronbach of 0.79. [39] The first item in the questionnaire was used to assess the type and frequency of sports and/or dance activities in which the adolescents took part. The second to eighth were used to assess the activity of the adolescents during physical education classes, recess, lunchtime,

immediately after school, in the evenings, at the weekend and during leisure time. A five-point Likert scale 1 [lowest] to 5 [highest] was used for the second to eighth items. The ninth item was used to assess their physical activity frequency. The tenth item was used to gather information on any unusual activities that the adolescents undertook during those 7 days. The results obtained from the PAQ-C were categorised following Crocker et al (1997) into low (<2.33), moderate (2.33-3.66) and high (>3.66).[40]

Anthropometric measures

Body weight was measured by using a digital electronic weighing scale (Seca 813, Seca, UK) and recorded to the nearest 0.1 kg. Height was measured without socks and shoes by using a calibrated vertical stadiometer (Seca Portable 217, Seca, UK) and recorded to the nearest 0.1 cm. Body mass index was calculated as weight in kilograms divided by the square of height in metres. Waist circumference (midpoint between the lowest rib margin and the iliac crest) was measured by using a non-elastic measuring tape (Seca 201, Seca, UK) and recorded to the nearest 0.1 cm. Percentage body fat was measured by using a bioelectric impedance analyser (SC-240, Body Composition Analyser, Tanita Europe BV, The Netherlands).

Sociodemographic measures

Sociodemographic measures were collected via parental and student questionnaires which included questions on age, ethnicity and place of residency.

Statistical analyses

Analyses were performed using the Statistical Package for Social Sciences software for Windows version 22.0 (IBM, Chicago, IL, USA) and the significance level was set at $p<0.05$. The analyses were performed separately by gender. Normality and skewness tests were used to assess normal distribution. All variables showed a normal distribution, except for weight, waist circumference and BMI. Data was presented as means and standard deviations for normally distributed continuous variables, medians and interquartile ranges (IQRs) for non-normally distributed continuous variables and percentages for categorical variables. The independent t-test was used to examine gender differences for normally distributed variables and the Mann-Whitney U test was used for non-normally distributed variables. The association between hand grip strength and (i) energy intake, (ii) macronutrient intake and (iii) physical activity score was assessed by using Pearson's correlation coefficient. The hand grip strength of the dominant hand was entered as the dependent variable and (i) energy and macronutrient intake and (ii) physical activity score were entered as the independent variables while controlling for ethnicity, place of residency and BMI. Body mass index was chosen as the covariate despite there being several other indicators of obesity because BMI is able to discriminate body fatness in adolescents.[41] In addition, linear regression

was used to investigate whether dietary intake and physical activity could predict hand grip strength when controlling for ethnicity, place of residency and BMI.

Patient and public involvement

An information sheet and consent forms were given to the students and their parents/guardian prior to recruitment. Participation in the study was on a voluntary basis. A feasibility study was done prior to the actual study and its findings assisted in ensuring the flow of the actual study and data collection. Each participant was given a record book in which the relevant results such as weight, height and hand grip strength were recorded.

RESULTS

Descriptive analysis

Table 1 provides the characteristics of the participants. It can be seen that males had significantly higher values than females in terms of weight, physical activity score, hand grip strength of both hands, and energy and carbohydrate intakes per day, but not in percentage body fat and BMI ($p<0.05$). About two thirds (69.2%) of the females had a low physical activity score, whereas almost two thirds of the males (65.2%) had a moderate to high physical activity score.

Correlation and regression

Table 2 shows that a positive linear relationship was found between energy, carbohydrate, and fat intakes and physical activity score and the dependent variable hand grip strength ($p<0.001$) among males. However, no such correlation was found in females.

To investigate whether dietary intake and physical activity could predict hand grip strength, a linear regression was computed while controlling for ethnicity, place of residency and BMI. Before running the regressions, the assumptions of linearity, normally distributed errors and non-correlated errors were checked and met. When the physical activity score and energy intake were added, both variables significantly predicted hand grip strength: $F(3, 391) = 26.318$, $p<0.001$, adjusted $R^2 = 0.162$ (Table 3). When physical factors (length of dominant hand span and height) were entered, the prediction improved with an adjusted R^2 of 0.339.

Table 1: Characteristics of MyHeART participants

		Male (n=395)	Female (n=617)	All (n=1012)	*p*
Age (y)		15.04 (±0.198)	15.04 (±0.205)	15.04 (±0.202)	0.384
Ethnicity					
	Malay	307 (77.7%)	487 (78.9%)	795 (78.6%)	0.495
	Chinese	26 (6.6%)	47 (7.6%)	73 (7.2%)	
	Indian	35 (8.9%)	54 (8.8%)	89 (8.8%)	
	Others	27 (6.8%)	29 (4.7%)	56 (5.5%)	
Place of residency					
	Urban	216 (54.7%)	367 (59.5%)	583 (57.6%)	0.132
	Rural	179 (45.3%)	250 (40.5%)	429 (42.4%)	
Weight[a] (kg)		*51.00 (17.00)*	*48.50 (15.35)*	*49.50 (15.60)*	<0.001*
Height (cm)		163.20 (±6.76)	154.65 (±5.67)	157.99 (±7.40)	0.052
BMI[a] (kg/m2)		*18.90 (5.49)*	*20.25 (5.74)*	*19.74 (5.73)*	<0.001*
% body fat		15.50 (±11.02)	29.37 (±9.17)	23.95 (±12.01)	<0.001*
Waist circumference[a] (cm)		*67.90 (15.50)*	*69.00 (13.50)*	*68.50 (14.00)*	0.514

Differences between male and female participants were determined using an independent t-test and the Mann-Whitney test. Data are presented as means ± standard deviation or as n (%), unless otherwise stated.

**Statistically significant at p<0.05.*

[a]*Values are expressed as medians (IQRs).*

Table 1: Characteristics of MyHeART participants (cont…)

	Male (n=395)	Female (n=617)	All (n=1012)	*p*
Physical activity score	2.43 (±0.75)	2.12 (±0.54)	2.24 (±0.65)	<0.001*
Physical activity level				
low (<2.33)	177 (44.8%)	427 (69.2%)	604 (59.7%)	<0.001*
moderate (2.33-3.66)	199 (50.4%)	183 (29.7%)	382 (37.7%)	
high (>3.66)	19 (4.8%)	7 (1.1%)	26 (2.6%)	
Hand grip strength (kg)				
Average hand grip strength (dominant hand) (kg)	27.25 (±7.16)	18.73 (±4.63)	22.06 (±7.09)	<0.001*
Average hand grip strength (non-dominant hand) (kg)	25.77 (±7.34)	17.44 (±4.72)	20.69 (±7.15)	
Energy & macronutrients intake				
Energy (kcal)	2047 (±583)	1738 (±474)	1858 (±540)	0.001*
Protein (g)	75.69 (±22.48)	66.07 (±19.45)	69.82 (±21.20)	0.04*
Protein (g/kg)	1.46 (±0.58)	1.35 (±0.53)	1.40 (±0.55)	0.168
Carbohydrate (g)	280.71 (±90.17)	229.31 (±67.79)	249.37 (±81.23)	<0.001*
Fat (g)	68.97 (±21.74)	61.60 (±20.13)	64.48 (±21.07)	0.16

Differences between male and female participants were determined using an independent t-test and the Mann-Whitney test. Data are presented as means ± standard deviation or as n (%), unless otherwise stated.

**Statistically significant at p<0.05.*

[a]Values are expressed as medians (IQRs).

Table 2: Partial correlation (r) between dietary intake, physical activity score and hand grip strength in adolescents

	Hand grip strength for males* (n = 395)		Hand grip strength for females* (n = 617)	
	r	**P**	**r**	**p**
Energy and macronutrients intake				
Energy (kcal)	0.140	0.006**	0.018	0.651
Protein (g/kg)	-0.134	0.008**	-0.021	0.610
Carbohydrate (g)	0.153	0.002**	0.026	0.528
Fat (g)	0.124	0.014**	-0.002	0.962
Physical activity score	0.170	0.001**	0.042	0.298

**Controlled for ethnicity, place of residency and BMI*

***Statistically significant at p<0.05.*

Table 3: Multiple linear regression model for male adolescents

	Hand grip strength of male (n = 395)		
	R^2	**β**	**p**
	0.162		
Energy intake (kcal)		0.143	0.002*
Physical activity score		0.129	0.006*

**Controlled for ethnicity, place of residency and BMI*

DISCUSSION

Hand grip strength, dietary intake and physical activity

This study showed that the muscle strength of Malaysian adolescents is much lower than that of their counterparts as reported by studies in Europe (males:35.9kg; females:26.2kg), the United Kingdom (males:25.7kg; females:21.8kg) and Colombia of South America (males:33.6kg; females:24.9kg).[9 15 42] Also, according to the results, female adolescents in Malaysia have lower muscle strength than those in Beijing, China.[43] Unfortunately, there is no large population based Asian male adolescent data with which to compare with the results of the current study. Hence, this study can be considered the first documented muscle strength study among adolescents of both genders in Asia. Nevertheless, despite the lack of comparable studies, the trend for adolescents is similar to that reported for Malaysian adult population, where it was found the hand grip strength of Malaysian adults is 1.5 times lower than that of adults in Western countries.[44] Thus together with the findings of the current study, this may indicate that the muscle strength of the Malaysian population is relatively low from a young age. Indeed, the results of a longitudinal study conducted in Quebec, a province in eastern Canada, which tracked muscle strength from childhood to adulthood, suggested that low muscle strength can persist from childhood through adolescence and into adulthood.[45] Therefore, it seems worthwhile to detect low muscle strength at a young age and build it up in order to foster favourable health outcomes in later life.[1] Thus, it can be argued that low muscle strength among adolescents warrants particular attention in order to identify the root cause, especially if it is associated with dietary intake and physical activity which are both modifiable health-related behaviours.

The results of this study also showed that there were differences in hand grip strength, dietary intake and physical activity score between male and female adolescents. Specifically, the males had higher muscle strength, consumed more energy, protein and carbohydrate and were more physically active than their female counterparts. These findings are consistent with those of previous studies conducted on study populations aged 13 years-old.[14 46 47]

Association between dietary intake, physical activity and hand grip strength

In this study, in males, energy, carbohydrate, and fat intakes and physical activity score were positively correlated with hand grip strength, but protein was weakly correlated (table 2). Although it has been shown that protein helps muscle protein synthesis and thus eventually improves muscle strength[48], the effect of protein was not observed in this study. One possible explanation for this finding could be due to quality of protein consumed.[49] Often, dietary protein is ingested as a whole so it includes high biological value and low biological value and this leads to difficulty in identifying how proteins derived from animal and plant sources differ in their capacity to improve muscle mass and strength. Empirical studies have shown that at least 25 g of high quality proteins (including at least 8-10 g essential amino acids and higher leucine content) promote muscle protein

synthesis and thus result in better muscle strength.[48] Therefore, the specific impact of high biological value protein is worth investigating in the future.

In addition, studies have also reported that energy plays a moderating role in muscle strength.[22 23] Although a study that used milk supplementation and resistance training as an intervention did not see an improvement in muscle mass, the researchers argued that energy plays a mediator role in the relationship between muscle mass, protein intake and resistance training despite the finding showing otherwise.[23] Therefore, a sufficient intake of energy and/or carbohydrate to meet the daily requirement is needed before protein can play a role in promoting muscle building and strength.

In the current study, when the energy intake per day and physical activity score were added into the model while controlling for BMI, both of these predictors remained significantly associated with hand grip strength. In addition, a higher energy intake and a higher physical activity score predicted a higher hand grip strength. Moreover, a higher BMI predicted a higher hand grip strength. The latter finding is consistent with that reported by a study on Southern Brazil adolescents, which found that the higher the BMI the greater the muscle strength.[21] Also, the researchers stated that their study population had a higher body mass, particularly muscle. As the current study did not include an objective measure for muscle mass, we considered body fat percentage and it was found that the male participants had a lower body fat percentage than the female participants. In addition, the average BMI of the (15-year-old) male participants was below the overweight level using International Obesity Task Force reference. Nevertheless, BMI is not generally regarded as a good indicator of body composition.[50] On the other hand, there is a general consensus that the higher the body fat, especially abdominal fat, the lower the hand grip strength.[5] This could be due to fat playing an inert role in muscle strength.[51] However, in contrast to the above-mentioned studies, a study conducted in Italy on a sample of 2411 adolescents produced a neutral result, implying that obesity does not affect muscle strength among healthy schoolchildren.[52] Nonetheless, the predictive equation used in the current study needs to be interpreted with caution as energy intake and physical activity only explain about 16.2% of the variation in muscle strength.

In this study, no relationship was found between dietary intake, physical activity score and hand grip strength among female adolescents. This result is similar to that reported in a study on adolescents in Europe[15], which showed that proline (amino acids) is positively correlated with lower limb muscular strength but that, when carbohydrate intake is controlled for, this relationship disappears.[15] On the other hand, a study conducted among Kenya adolescents found that female adolescents have greater muscle strength than their male counterparts and suggested that thi was because the females undertake more household chores such as transferring water from deep wells and preparing meals, and thus have greater access to food than the males.[53] All such activities eventually help to build upper limb muscle strength. However, these conditions are not commonly found in Malaysia where most adolescents are school attendees. It is therefore postulated that the reason that female adolescents in this study had lower muscle strength than the males is because almost 70% of the females had a low physical activity score due to a predominantly sedentary lifestyle as compared to the males, 65% of whom had a moderate to high physical activity score.

It has also been found by a previous study that females already have a lower physical activity score at an earlier age compared to males[46] and that this continues as they age.

Another possible reason for the significant result observed in males but not females could be due to changes with puberty stage, where the hand grip strength of males increases tremendously at this stage as compared to females. A study has reported that at 13 years old, the hand grip strength of males and females is 17.8 kg and 14.7 kg, respectively[14]. Greater muscle hypertrophy is commonly found in pre-adolescent males compared with females at the same growth stage because of increasing levels of circulating androgens in the males.[54] Moreover, it has also been found that muscle strength increases when a male reaches puberty, which it has been argued is related to the growth spurt due to the direct action of testosterone, which has a direct anabolic effect on muscle fibres.[55] In the population analysed in the current study, the majority (95%) of the males has reported that they had reached the puberty stage. Thus, in addition to the males being moderately to highly physically active, the presence of testosterone could explain the marked difference in muscle strength between the male and female participants.

Although a positive effect of protein on muscle strength was not seen in this study, it is still crucial to explore the effect of dietary protein as it is known to play a role in ensuring appropriate growth during adolescence.[15] Furthermore, muscle building only occurs when a person is physically active because such activity triggers the digestion and better absorption of amino acids,[49 56] which eventually increases muscle strength. Moreover, it is crucial to ensure that energy and carbohydrate intake requirements are met before protein can even play a role in improving muscle strength. The above findings therefore indicate that there is a strong need to undertake a longitudinal study to explore whether changes in dietary intake have an impact on hand grip strength among adolescents, and such a study also needs to takes into account the variables of physical activity and weight status.

It is also important to acknowledge that the type of physical activity may have an influence on the hand grip strength. A cross-sectional study has suggested different types of physical activity influence hand grip strength rather than the amount of time spent in physical activity per se.[57] Often, studies on muscle strength have included obesity parameters such as BMI and percentage body fat. Some of these studies have found that obese adolescents exhibit lower relative muscle strength to body mass as compared to their non-obese counterparts.[6 51] Some studies have found otherwise.[8 52 58] For instance, one such study reported that girls with normal BMI have a low hand grip strength as compared to overweight/obese girls,[8] and the author postulated that the overweight/obese females may have increased their muscle mass due to physical growth. However, this findings and postulation needs to be interpreted cautiously because BMI does not differentiate between fat mass and fat-free mass. Moreover, the finding of that study could be due to discrepancies when examining the absolute strength and muscle strength relative to muscle mass and muscle quality. Besides dietary and physical activity factors, the literature has also shown that physical factors such as height and length of hand span can influence hand grip strength.[21 59 60] Although assessing the influence of physical factors was not one of this study's objectives, physical factors were found to play a role in influencing hand grip strength.

Strengths and limitations

This study has a number of strengths. Firstly, it was conducted using a large sample of adolescents. Secondly, it used the standard protocols for hand grip strength, dietary intake and physical activity assessment as well as data monitoring processes during data collection, data entry and data analysis in order to minimise the risk of bias. Moreover, to the best of the authors's knowledge, this study may be the first to investigate the association between hand grip strength, dietary intake and physical activity among adolescents in Asia. However, it should be noted that this study is somewhat limited because it was cross-sectional in design, so the presence or otherwise of a causal relationship could not be established. In addition, the sample covered a narrow age range. Also, several variables such as dietary intake, physical activity and maturity stages were collected via self-completed questionnaire, which may be a limitation due to the potential for misreporting. However, no method is without its limitations and this method was pilot tested on adolescents, it was expected that it would be a reasonable approach. First, seven-day dietary record seemed the most appropriate in view of adolescents memory processing capability[29] and because other approaches such as indirect calorimetry were not possible in this population-based study. Second, the translated PAQ-C had previously been validated in a local setting.[39] Third, the self-reported puberty stage has been found to be reliable in a school-based survey with a weighted kappa coefficient of 0.68 for males and females.[61]

CONCLUSION

The findings of this study suggest that muscle strength is associated with energy intake and physical activity among males. However, this relationship was not found in females. This difference requires further investigation in order to gain a better understanding of the issues affecting muscle strength so as to improve the provision of nutritional and physical activity strategies for the adolescent muscular health of both genders.

ABBREVIATIONS

BMI Body Mass Index

IQR Interquartile range

Acknowledgments: The authors would like to thank Associate Professor Dr. Mohd Nahar Azmi Mohamed and Dr. 'Abqariyah Binti Yahya for the support and guidance.

Contributors: AK Ng, HA Majid and NN Hairi carried out the data analysis. AK Ng drafted the manuscript. HA Majid and MY Jalaludin contributed in the design of the study and data collection. All authors contributed to the final manuscript write up.

Funding: This study was supported by funding received from the University Malaya's Research Programme (UMRP022A-14HTM) and Postgraduate Research Fund (PG026-2016A).

Competing interests: None.

Ethical approval: Ethics Committee of the University Malaya Medical Centre (MEC Ref. No. 896.34).

Data availability statement: All data relevant to the study are included in the article or uploaded as supplementary information.

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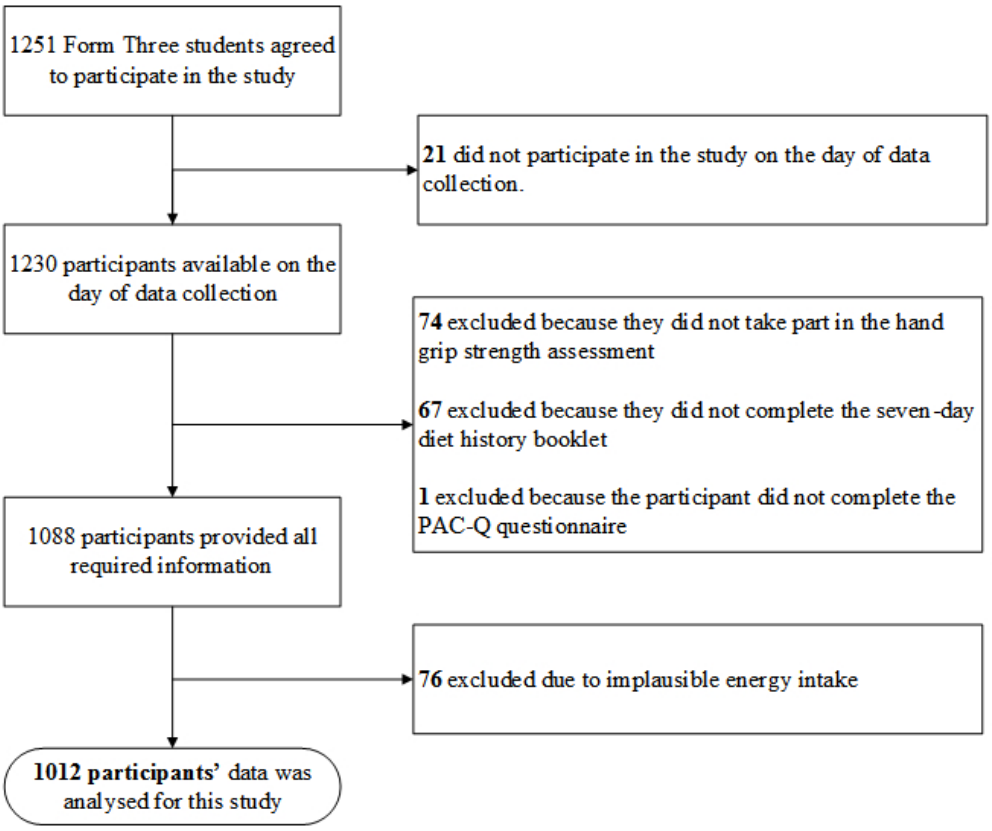

Flowchart of the participant sampling procedure

173x143mm (96 x 96 DPI)

STROBE 2007 (v4) checklist of items to be included in reports of observational studies in epidemiology*

Checklist for cohort, case-control, and cross-sectional studies (combined)

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	1
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	3
Objectives	3	State specific objectives, including any pre-specified hypotheses	3
Methods			
Study design	4	Present key elements of study design early in the paper	4
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	4
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	4
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	Not applicable
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	4-5
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	4-5
Bias	9	Describe any efforts to address potential sources of bias	Not applicable
Study size	10	Explain how the study size was arrived at	4
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	6
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	6
		(*b*) Describe any methods used to examine subgroups and interactions	6
		(*c*) Explain how missing data were addressed	Not applicable
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed	Not applicable

		Cross-sectional study—If applicable, describe analytical methods taking account of sampling strategy	
		(*e*) Describe any sensitivity analyses	Not applicable
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	6
		(b) Give reasons for non-participation at each stage	6
		(c) Consider use of a flow diagram	Not applicable
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	6, 8-9
		(b) Indicate number of participants with missing data for each variable of interest	6
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	Not applicable
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	Not applicable
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	Not applicable
		Cross-sectional study—Report numbers of outcome events or summary measures	Not applicable
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	6-7, 10
		(*b*) Report category boundaries when continuous variables were categorized	Not applicable
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	Not applicable
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	Not applicable
Discussion			
Key results	18	Summarise key results with reference to study objectives	11-13
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	13
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	13
Generalisability	21	Discuss the generalisability (external validity) of the study results	13
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	14

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

Dietary intake, physical activity and muscle strength among adolescents: the Malaysian Health and Adolescents Longitudinal Research Team (MyHeART) study

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2018-026275.R2
Article Type:	Research
Date Submitted by the Author:	17-Apr-2019
Complete List of Authors:	Ng, Ai Kah; University of Malaya, Faculty of Medicine, Department of Social and Preventive Medicine; International Medical University, School of Health Sciences, Nutrition and Dietetics Department Hairi, Noran; University of Malaya, Faculty of Medicine, Centre for Epidemiology & Evidence-Based Practice and Department of Social and Preventive Medicine Jalaludin, Muhammad Yazid; University of Malaya, Faculty of Medicine, Department of Paediatrics Majid, Hazreen; University of Malaya, Faculty of Medicine, Department of Social and Preventive Medicine; Harvard University T H Chan School of Public Health, Nutrition
Primary Subject Heading:	Public health
Secondary Subject Heading:	Paediatrics, Nutrition and metabolism
Keywords:	Hand grip strength, Dietary intake, Adolescents, Physical activity, muscle strength

Research article

Dietary intake, physical activity and muscle strength among adolescents: the Malaysian Health and Adolescents Longitudinal Research Team (MyHeART) study

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Word Count, excluding title page, abstract, references, figures and tables: 4000 words.

Tables: 3

Figure: 1

Funding Statement: This study was supported by funding received from the University Malaya's Research Programme (UMRP022A-14HTM) and Postgraduate Research Fund (PG026-2016A).

Funding

University of Malaya Research Grant (UMRP022A-14HTM), UMSC grant cycle 1-2016 and all the school children who participated in this study. The funding bodies did not contribute to the design of the study, data collection, analysis, or interpretation of data.

Disclosure: The authors declare that they have no conflict of interests.

Author Contributions/ Statement of authorship: AK Ng, HA Majid and NN Hairi carried out the data analysis. AK Ng drafted the manuscript. HA Majid and NN Hairi contributed in the design of the study. HA Majid and MY Jalaludin involved with the data collection. All authors contributed to the final manuscript write up.

Ethics approval and consent to participate

Ethical approval was obtained from the Medical Ethics Committee, University Malaya Medical Centre (MEC Ref. No: 896.34). The National Medical Research Register number is 14-376-20486. Participation in the study was voluntary and written informed consent and ascent for participation in the study was obtained from the parents or guardian as well as the participants.

Title: Dietary intake, physical activity and muscle strength among adolescents: the Malaysian Health and Adolescents Longitudinal Research Team (MyHeART) study

ABSTRACT

Objective: To examine the role of dietary intake and physical activity in muscle strength among adolescents.

Design: Cross-sectional analysis.

Setting: The Malaysian Health and Adolescents Longitudinal Research Team (MyHeART) study.

Participants: Fifteen-year-old secondary school children who have given consent and who participated in the MyHeART study in 2014.

Primary outcome measure: Muscle strength was measured in relation to dietary intake (energy and macronutrients) and physical activity by using a hand grip dynamometer.

Results: Among the 1012 participants (395 male; 617 female), the hand grip strength of the males was higher than that of the females (27.08 kg vs 18.63 kg; $p<0.001$). Also, males were more active (2.43 vs 2.12; $p<0.001$) and consumed a higher amount energy (2047 kcal vs 1738 kcal, $p<0.001$), carbohydrate (280.71 g vs 229.31 g; $p<0.001$) and protein (1.46g/kgBW vs 1.35g/kgBW; $p<0.168$). After controlling for ethnicity, place of residency and body mass index (BMI), there was a positive relationship between hand grip strength and the intake of energy ($r=0.14$; $p=0.006$), carbohydrate ($r=0.153$; $p=0.002$) and fat ($r=0.124$; $p=0.014$) and the physical activity score ($r=0.170$; $p=0.001$) and a negative relationship between hand grip strength and the intake of protein ($r=-0.134$; $p=0.008$), for males. However, this was not observed among females.

Conclusions: Energy, carbohydrate and fat intakes and physical activity score were positively correlated with hand grip strength while protein intake was negatively correlated with hand grip strength in males but not in females.

Keywords: Muscle strength, Hand grip strength, Dietary intake, Physical activity, Adolescents

ARTICLE SUMMARY

Strengths and limitations of this study

- The main strengths of this study are that it used a large sample of adolescents and the standardised measurement of muscle strength.
- This study is also the first to investigate the association between dietary intake, physical activity and muscle strength among adolescents in Asia.
- The main limitations of this study are that the sample covers a limited age range and the cross-sectional design of the study does not allow any causality interpretations.

INTRODUCTION

Recent research has paid much attention to poor muscles strength among adolescents and its association with adverse health-related outcomes, including cardiovascular disease,[1] poorer metabolic profile,[2-4] obesity[5 6] and musculoskeletal pain[7] as well as premature death from any cause.[1] Furthermore, a cross-sectional study among adolescents in a city in southern Brazil reported a prevalence of low muscle strength of 47% among the study population.[8] Moreover, most studies have suggested that there is a declining trend of muscle strength among adolescents over time[9-12] except for a study conducted in Colombia[13] that indicated otherwise. The study in Colombia, a middle-income country, also found that, adolescents have a lower hand grip strength compared to those in high-income countries.[13] Similarly, a preliminary finding from the MyHeART study showed that Malaysian adolescents have a lower handgrip strength than those in other countries.[9 14 15] However, it was not possible to categorise the hand grip strength of Malaysian adolescents based on the cutoff values used[8] as there were no available normal values for Asian adolescents. Moreover, the published cutoff values should not be used as the reference standard for Asian populations because most Asians are not able to achieve the published cutoff values.[16]

Issues pertaining to unhealthy dietary intake[17] and low physical activity[18] among adolescents are well documented worldwide,. In fact, dietary intake and/or low physical activity are increasingly recognised to be modifiable health-related behavioural determinants of muscle strength among adolescents.[15 19-21] the results reported by population-based cohort studies regarding the effect of energy and macronutrient intake are limited at this point in time.[15 22] For instance, a cross-sectional study that was conducted among European adolescents found that specific amino acids are associated with muscle strength; however, when carbohydrate is controlled for, these relationships disappear. [15] Another cohort study from India in which pregnant women and children were given a balanced protein-calorie supplementation and the children were followed up at adult stage, also emphasised the importance of an adequate energy intake in order to increase muscle strength. The cohort study also found that energy intake and physical activity are positively associated with muscle strength.[22] Furthermore, an experimental study on adolescents found that milk supplementation with resistance training does not change body composition.[23] However, the authors argued that it could be due to energy intake playing a vital role in the relationship between body composition, resistance training and the effect of these factors on both muscle mass and strength.[23]

In view of the changes that take place in the skeletal muscle in response to energy and macronutrient intake particularly carbohydrate and protein intake, in normal physiology[24], it is worthwhile to further investigate the relationship between dietary intake, particularly energy and macronutrients, and muscle strength. While previous studies have provided some evidences to demonstrate that low level of physical activity[8 25] and being overweight[8] are associated with low hand grip strength, there was only a study by Gracia-Marco et al (2017) has evaluated the effect of amino acids (dietary protein) and physical activity on hand grip strength. [15] It seems that no study have evaluated the influence of dietary intake and physical activity on hand grip strength among adolescents specifically. Thus, the relationship between dietary intake, physical activity and muscle strength among adolescents is not yet well understood. Moreover, to the best of the

authors' knowledge, only a limited number of studies have investigated the association between hand grip strength, dietary intake and/or physical activity among adolescents, particularly in Asia. Therefore, the purpose of this paper is to examine the association between hand grip strength, dietary intake and physical activity among adolescents in Malaysia.

METHODS

This cross-sectional study is a secondary analysis of data derived from the first follow-up of the Malaysian Health and Adolescents Longitudinal Research Team (MyHeART) study. The population for the current study was comprised of 15-year-old adolescents attending public secondary schools in the central and northern regions of Peninsular Malaysia. The sampling method used was multistage random sampling. The primary sampling units were the schools and the secondary sampling units were the students. In the first stage, the study frame was a complete list of public schools in the two above-mentioned regions from which total of 15 public secondary schools were selected. In the second stage, the defined study population was selected from a complete list of Form Three students in each of the selected school. Full details of the original MyHeART study protocol have been published elsewhere.[26]

In 2014, 1230 adolescents were recruited for the MyHeART study. Out of the total participants in 2014, 1012 (82.3%) were included in the analysis for this paper. A flowchart of the sampling procedure used to select the participants for this study is provided in Figure 1.

The MyHeART study was approved by the Ethics Committee of the University Malaya Medical Centre (MEC Ref. No. 896.34). Subsequently, formal approval was obtained from the Ministry of Health and Ministry of Education and then approval was sought from the relevant state level administrative authorities before approaching the Headmasters and Headmistresses of the selected schools.

The data collection was conducted by the MyHeART team, which was led by the principal investigator. The team consisted of 20 research assistants (medical doctors, nurses and dietitians) who collected the data at various stations such as anthropometry, hang grip strength and dietary stations. The data was collected between March and May in 2014. Prior to conducting data collection, Principle Investigator provided orientation and training sessions for the research assistants in order to familiarise them with the objectives and methodology of the study as well as hands-on practice in measuring the anthropometrics and hand grip strength. In addition, the researcher assistants who were dietitians received training on how to conduct the seven-days diet history using standardised portion of food and how to translate the diet history into a coding sheet in order to ensure the consistency and quality of the collected data.

Muscle strength

Hand grip strength has been shown to have moderate to strong validity and high reliability in tests for upper body and lower body strength in adolescents.[27] Moreover, hand grip strength has been found to be valid, reliable and feasible for school setting.[28] Therefore muscle strength was assessed by using hand grip strength. A calibrated hand dynamometer (Jamar, Sammons Preston Rolyan, Illinois, US), whose unit of measurement is the kilogram, was used in the assessment of hand grip strength. The strength of the dominant and the non-dominant hand was recorded. Prior to the measurements being taken, the dynamometer was calibrated. Then, it was adjusted for different hand sizes. Participants were gathered in a hall. Each participant was positioned in a straight back chair with both feet flat on the ground. The elbow was flexed to 90^{o} with forearm and wrist were in neutral position. The measurement began with dominant hand once the dominant hand was identified. The measurement followed by the non-dominant hand. The dominant and non-dominant hands of the participants were each tested three times and the readings were recorded to the nearest 0.1 kg.[29] The average of the three readings for the dominant hand was used in analysis. All the measurements were done by trained research assistants.

Dietary intakes

Dietary intake was assessed by using a 7-day diet history. The diet history is the best method by which to estimate adolescents' intakes because they can better recall what they have eaten and drunk and this history can thus reveal more accurate information about their overall intakes.[30] This method also shows less variation in dietary assessment from the epidemiological perspective[31] and is more representative of adolescents' habitual intakes than other methods.[32 33] The seven-day diet history was collected by trained research assistants who were qualified dietitians. The *Nutrient Composition of Malaysian Food* (4th edition)[34] was used to calculate energy and macronutrient intakes and the values were entered into the Nutritionist ProTM database (Axxya Systems, USA).[34] The intakes from food items and recipes that could not be found in the *Nutrient Composition of Malaysian Food* were calculated on the basis of the details provided by the food packaging and the recipe. These calculations were then entered into the database by adjusting them based on standard recipes (per serving size). After the diet history had been analysed, 10% of the data was randomly cross-checked by an independent qualified dietitian who was not involved in analysing the dietary data. The margin of error was 4.4%. It was seemed acceptable as it has been stated that a 10% margin of error is acceptable.[35] Total of 76 participants with implausible energy intakes (<500 kcal/day or >5000 kcal/day) were excluded from this analysis.[36]

Physical activity score

A Malay version of the validated physical activity questionnaire for older children (PAQ-C) consisting of 10 items was used to obtain the physical activity level of the adolescents over the past 7 days. The PAC-Q questionnaire has been shown to be valid and to have good internal consistency.[37-39] The translated version has been validated in a local setting. [40] The first item in the

questionnaire was used to assess the type and frequency of sports and/or dance activities in which the adolescents took part. The second to eighth were used to assess the activity of the adolescents during physical education classes, recess, lunchtime, immediately after school, in the evenings, at the weekend and during leisure time. A five-point Likert scale 1 [lowest] to 5 [highest] was used for the second to eighth items. The ninth item was used to assess their physical activity frequency. The tenth item was used to gather information on any unusual activities that the adolescents undertook during those 7 days. The results obtained from the PAQ-C were categorised following Crocker et al (1997) into low (<2.33), moderate (2.33-3.66) and high (>3.66).[41]

Anthropometric measures

Body weight was measured by using a digital electronic weighing scale (Seca 813, Seca, UK) and recorded to the nearest 0.1 kg. Height was measured without socks and shoes by using a calibrated vertical stadiometer (Seca Portable 217, Seca, UK) and recorded to the nearest 0.1 cm. Body mass index was calculated as weight in kilograms divided by the square of height in metres. Waist circumference (midpoint between the lowest rib margin and the iliac crest) was measured by using a non-elastic measuring tape (Seca 201, Seca, UK) and recorded to the nearest 0.1 cm. Percentage body fat was measured by using a bioelectric impedance analyser (SC-240, Body Composition Analyser, Tanita Europe BV, The Netherlands).

Sociodemographic measures

Sociodemographic measures were collected via parental and student questionnaires which included questions on age, ethnicity and place of residency.

Statistical analyses

Analyses were performed using the Statistical Package for Social Sciences software for Windows version 22.0 (IBM, Chicago, IL, USA) and the significance level was set at $p<0.05$. The analyses were performed separately by gender. Normality and skewness tests were used to assess normal distribution. All variables showed a normal distribution, except for weight, waist circumference and BMI. Data was presented as means and standard deviations for normally distributed continuous variables, medians and interquartile ranges (IQRs) for non-normally distributed continuous variables and percentages for categorical variables. The independent t-test was used to examine gender differences for normally distributed variables and the Mann-Whitney U test was used for non-normally distributed variables. The association between hand grip strength and (i) energy intake, (ii) macronutrient intake and (iii) physical activity score was assessed by using Pearson's correlation coefficient. The hand grip strength of the dominant hand was entered as the dependent variable and (i) energy and macronutrient intake and (ii) physical activity score were entered as the independent variables while controlling for ethnicity, place of residency and BMI. Body mass index was chosen as the covariate despite there being several other indicators of obesity

because BMI is able to discriminate body fatness in adolescents.[42] In addition, linear regression was used to investigate whether dietary intake and physical activity could predict hand grip strength when controlling for ethnicity, place of residency and BMI.

Patient and public involvement

An information sheet and consent forms were given to the students and their parents/guardian prior to recruitment. Participation in the study was on a voluntary basis. A feasibility study was done prior to the actual study and its findings assisted in ensuring the flow of the actual study and data collection. Each participant was given a record book in which the relevant results such as weight, height and hand grip strength were recorded.

RESULTS

Descriptive analysis

Table 1 provides the characteristics of the participants. It can be seen that males had significantly higher values than females in terms of weight, physical activity score, hand grip strength of both hands, and energy and carbohydrate intakes per day, but not in percentage body fat and BMI ($p<0.05$). About two thirds (69.2%) of the females had a low physical activity score, whereas almost two thirds of the males (65.2%) had a moderate to high physical activity score.

Correlation and regression

Table 2 illustrates the main result and the number of participants used for the analysis which was as described in Figure 1. A positive linear relationship was found between energy, carbohydrate, and fat intakes and physical activity score and the dependent variable hand grip strength ($p<0.01$) among males. Meanwhile, protein (g/kg body weight) was found to be negatively correlated with hand grip strength among males ($p<0.01$). However, no such correlation was found in females.

To investigate whether dietary intake and physical activity could predict hand grip strength, a linear regression was computed while controlling for ethnicity, place of residency and BMI. Before running the regressions, the assumptions of linearity, normally distributed errors and non-correlated errors were checked and met. Protein, carbohydrate and fat intakes were not used in the regression due to multicollinearity. When the physical activity score and energy intake were added, both variables significantly predicted hand grip strength: $F(3, 391) = 26.318$, $p<0.001$, adjusted $R^2 = 0.162$ (Table 3). When physical factors (length of dominant hand span and height) were entered, the prediction improved with an adjusted R^2 of 0.339.

Table 1: Characteristics of MyHeART participants

		Male (n=395)	Female (n=617)	All (n=1012)	*p*
Age (y)		15.04 (±0.198)	15.04 (±0.205)	15.04 (±0.202)	0.384
Ethnicity					
	Malay	307 (77.7%)	487 (78.9%)	795 (78.6%)	0.495
	Chinese	26 (6.6%)	47 (7.6%)	73 (7.2%)	
	Indian	35 (8.9%)	54 (8.8%)	89 (8.8%)	
	Others	27 (6.8%)	29 (4.7%)	56 (5.5%)	
Place of residency					
	Urban	216 (54.7%)	367 (59.5%)	583 (57.6%)	0.132
	Rural	179 (45.3%)	250 (40.5%)	429 (42.4%)	
Weight[a] (kg)		*51.00 (17.00)*	*48.50 (15.35)*	*49.50 (15.60)*	<0.001*
Height (cm)		163.20 (±6.76)	154.65 (±5.67)	157.99 (±7.40)	0.052
BMI[a] (kg/m2)		*18.90 (5.49)*	*20.25 (5.74)*	*19.74 (5.73)*	<0.001*
BMI category					<0.001*
	Underweight	86 (21.8%)	108 (17.5%)	194 (19.2%)	
	Normal	222 (56.2%)	355 (57.5%)	577 (57.0%)	
	Overweight	51 (12.9%)	101 (16.4%)	152 (15.0%)	
	Obesity	36 (9.1%)	53 (8.6%)	89 (8.8%)	
% body fat		15.50 (±11.02)	29.37 (±9.17)	23.95 (±12.01)	<0.001*
Waist circumference[a] (cm)		*67.90 (15.50)*	*69.00 (13.50)*	*68.50 (14.00)*	0.514

Differences between male and female participants were determined using an independent t-test and the Mann-Whitney test. Data are presented as means ± standard deviation or as n (%), unless otherwise stated.

**Statistically significant at p<0.05.*

[a]*Values are expressed as medians (IQRs).*

Table 1: Characteristics of MyHeART participants (cont…)

	Male (n=395)	Female (n=617)	All (n=1012)	*p*
Physical activity score	2.43 (±0.75)	2.12 (±0.54)	2.24 (±0.65)	<0.001*
Physical activity level				
low (<2.33)	177 (44.8%)	427 (69.2%)	604 (59.7%)	<0.001*
moderate (2.33-3.66)	199 (50.4%)	183 (29.7%)	382 (37.7%)	
high (>3.66)	19 (4.8%)	7 (1.1%)	26 (2.6%)	
Hand grip strength (kg)				
Average hand grip strength (dominant hand) (kg)	27.25 (±7.16)	18.73 (±4.63)	22.06 (±7.09)	<0.001*
Average hand grip strength (non-dominant hand) (kg)	25.77 (±7.34)	17.44 (±4.72)	20.69 (±7.15)	<0.001*
Energy & macronutrients intake				
Energy (kcal)	2047 (±583)	1738 (±474)	1858 (±540)	0.001*
Protein (g)	75.69 (±22.48)	66.07 (±19.45)	69.82 (±21.20)	0.04*
Protein (g/kg)	1.46 (±0.58)	1.35 (±0.53)	1.40 (±0.55)	0.168
Carbohydrate (g)	280.71 (±90.17)	229.31 (±67.79)	249.37 (±81.23)	<0.001*
Fat (g)	68.97 (±21.74)	61.60 (±20.13)	64.48 (±21.07)	0.16

Differences between male and female participants were determined using an independent t-test and the Mann-Whitney test. Data are presented as means ± standard deviation or as n (%), unless otherwise stated.

**Statistically significant at p<0.05.*

[a]*Values are expressed as medians (IQRs).*

Table 2: Partial correlation (r) between dietary intake, physical activity score and hand grip strength in adolescents

	Hand grip strength for males* (n = 395)		Hand grip strength for females* (n = 617)	
	r	**P**	**r**	**p**
Energy and macronutrients intake				
Energy (kcal)	0.140	0.006**	0.018	0.651
Protein (g/kg)	-0.134	0.008**	-0.021	0.610
Carbohydrate (g)	0.153	0.002**	0.026	0.528
Fat (g)	0.124	0.014**	-0.002	0.962
Physical activity score	0.170	0.001**	0.042	0.298

**Controlled for ethnicity, place of residency and BMI*

***Statistically significant at p<0.05.*

Table 3: Multiple linear regression model for male adolescents

	Hand grip strength of male (n = 395)		
	R^2	**β**	**p**
	0.162		
Energy intake (kcal)		0.143	0.002*
Physical activity score		0.129	0.006*

**Controlled for ethnicity, place of residency and BMI*

DISCUSSION

Hand grip strength, dietary intake and physical activity

This study showed that the muscle strength of Malaysian adolescents is much lower than that of their counterparts as reported by studies in Europe (males: 35.9±9.3kg; females: 26.2±4.9kg), the United Kingdom (males: 25.7±kg; females: 21.8±5.8kg) and Colombia of South America (males: 33.6±6.85kg; females: 24.9±4.29kg).[2 15 43] Also, according to the results, female adolescents in Malaysia have lower muscle strength than those in Beijing, China.[44] Unfortunately, there is no large population based Asian male adolescent data with which to compare with the results of the current study. Hence, this study can be considered the first documented muscle strength study among adolescents of both genders in Asia. Nevertheless, despite the lack of comparable studies, the trend for adolescents is similar to that reported for Malaysian adult population, where it was found the hand grip strength of Malaysian adults is 1.5 times lower than that of adults in Western countries.[45] Thus together with the findings of the current study, this may indicate that the muscle strength of the Malaysian population is relatively low from a young age. Indeed, the results of a longitudinal study conducted in Quebec, a province in eastern Canada, which tracked muscle strength from childhood to adulthood, suggested that low muscle strength can persist from childhood through adolescence and into adulthood.[46] Therefore, it seems worthwhile to detect low muscle strength at a young age and build it up in order to foster favourable health outcomes in later life.[1] Thus, it can be argued that low muscle strength among adolescents warrants particular attention in order to identify the root cause, especially if it is associated with dietary intake and physical activity which are both modifiable health-related behaviours.

The results of this study also showed that there were differences in hand grip strength, dietary intake and physical activity score between male and female adolescents. Specifically, the males had higher muscle strength, consumed more energy, protein and carbohydrate and were more physically active than their female counterparts. These findings are consistent with those of previous studies conducted on study populations aged 13 years-old.[14 47 48]

Association between dietary intake, physical activity and hand grip strength

In this study, in males, energy, carbohydrate, and fat intakes and physical activity score were positively correlated with hand grip strength, but protein was negatively weak correlated (table 2). Although it has been shown that protein helps muscle protein synthesis and thus eventually improves muscle strength[49], the effect of protein was not observed in this study. One possible explanation for this finding could be due to quality of protein consumed.[50] Often, dietary protein is ingested as a whole so it includes high biological value and low biological value and this leads to difficulty in identifying how proteins derived from animal and plant sources differ in their capacity to improve muscle mass and strength. Empirical studies have shown that at least 25 g of high quality proteins (including at least 8-10 g essential amino acids and higher leucine content)

promote muscle protein synthesis and thus result in better muscle strength.[49] Therefore, the specific impact of high biological value protein is worth investigating in the future.

In addition, studies have also reported that energy plays a moderating role in muscle strength.[22 23] Although a study that used milk supplementation and resistance training as an intervention did not see an improvement in muscle mass, the researchers argued that energy plays a mediator role in the relationship between muscle mass, protein intake and resistance training despite the finding showing otherwise.[23] Therefore, a sufficient intake of energy and/or carbohydrate to meet the daily requirement is needed before protein can play a role in promoting muscle building and strength.

In the current study, when the energy intake per day and physical activity score were added into the model while controlling for BMI, both of these predictors remained significantly associated with hand grip strength. In addition, a higher energy intake and a higher physical activity score predicted a higher hand grip strength. Moreover, a higher BMI predicted a higher hand grip strength. The latter finding is consistent with that reported by a study on Southern Brazil adolescents, which found that the higher the BMI the greater the muscle strength.[21] Also, the researchers stated that their study population had a higher body mass, particularly muscle. As the current study did not include an objective measure for muscle mass, we considered body fat percentage and it was found that the male participants had a lower body fat percentage than the female participants. In addition, the average BMI of the (15-year-old) male participants was below the overweight level using International Obesity Task Force reference. Nevertheless, BMI is not generally regarded as a good indicator of body composition.[51] On the other hand, there is a general consensus that the higher the body fat, especially abdominal fat, the lower the hand grip strength.[5] This could be due to fat playing an inert role in muscle strength.[52] However, in contrast to the above-mentioned studies, a study conducted in Italy on a sample of 2411 adolescents produced a neutral result, implying that obesity does not affect muscle strength among healthy schoolchildren.[53] Nonetheless, the predictive equation used in the current study needs to be interpreted with caution as energy intake and physical activity only explain about 16.2% of the variation in muscle strength.

In this study, no relationship was found between dietary intake, physical activity score and hand grip strength among female adolescents. This result is similar to that reported in a study on adolescents in Europe[15], which showed that proline (amino acids) is positively correlated with lower limb muscular strength but that, when carbohydrate intake is controlled for, this relationship disappears.[15] On the other hand, a study conducted among Kenya adolescents found that female adolescents have greater muscle strength than their male counterparts and suggested that thi was because the females undertake more household chores such as transferring water from deep wells and preparing meals, and thus have greater access to food than the males.[54] All such activities eventually help to build upper limb muscle strength. However, these conditions are not commonly found in Malaysia where most adolescents are school attendees. It is therefore postulated that the

reason that female adolescents in this study had lower muscle strength than the males is because almost 70% of the females had a low physical activity score due to a predominantly sedentary lifestyle as compared to the males, 65% of whom had a moderate to high physical activity score. It has also been found by a previous study that females already have a lower physical activity score at an earlier age compared to males[47] and that this continues as they age.

Another possible reason for the significant result observed in males but not females could be due to changes with puberty stage, where the hand grip strength of males increases tremendously at this stage as compared to females. A study has reported that at 13 years old, the hand grip strength of males and females is 17.8 kg and 14.7 kg, respectively[14]. Greater muscle hypertrophy is commonly found in pre-adolescent males compared with females at the same growth stage because of increasing levels of circulating androgens in the males.[55] Moreover, it has also been found that muscle strength increases when a male reaches puberty, which it has been argued is related to the growth spurt due to the direct action of testosterone, which has a direct anabolic effect on muscle fibres.[56] In the population analysed in the current study, the majority (95%) of the males has reported that they had reached the puberty stage. Thus, in addition to the males being moderately to highly physically active, the presence of testosterone could explain the marked difference in muscle strength between the male and female participants.

Although a positive effect of protein on muscle strength was not seen in this study, it is still crucial to explore the effect of dietary protein as it is known to play a role in ensuring appropriate growth during adolescence.[15] Furthermore, muscle building only occurs when a person is physically active because such activity triggers the digestion and better absorption of amino acids,[50 57] which eventually increases muscle strength. Moreover, it is crucial to ensure that energy and carbohydrate intake requirements are met before protein can even play a role in improving muscle strength. The above findings therefore indicate that there is a strong need to undertake a longitudinal study to explore whether changes in dietary intake have an impact on hand grip strength among adolescents, and such a study also needs to takes into account the variables of physical activity and weight status.

It is also important to acknowledge that the type of physical activity can affect the hand grip strength. A cross-sectional study has suggested different types of physical activity influence hand grip strength and not the amount of time spent on physical activity.[58] Often, studies on muscle strength have included obesity parameters such as BMI and percentage body fat. Some of these studies have found that obese adolescents exhibit lower relative muscle strength to body mass as compared to their non-obese counterparts.[6 52] Some studies have found otherwise.[8 53 59] For instance, one such study reported that girls with normal BMI have a low hand grip strength as compared to overweight/obese girls,[8] and the author postulated that the overweight/obese females may have increased their muscle mass due to physical growth. However, this findings and postulation needs to be interpreted cautiously because BMI does not differentiate between fat mass

and fat-free mass. Moreover, the finding of that study could be due to discrepancies when examining the absolute strength and muscle strength relative to muscle mass and muscle quality. Besides dietary and physical activity factors, the literature has also shown that physical factors such as height and length of hand span can influence hand grip strength.[21 60 61] Although assessing the influence of physical factors was not one of this study's objectives, physical factors were found to play a role in influencing hand grip strength.

Strengths and limitations

This study has a number of strengths. Firstly, it was conducted using a large sample of adolescents. Secondly, it used the standard protocols for hand grip strength, dietary intake and physical activity assessment as well as data monitoring processes during data collection, data entry and data analysis in order to minimise the risk of bias. Moreover, to the best of the authors's knowledge, this study may be the first to investigate the association between hand grip strength, dietary intake and physical activity among adolescents in Asia. However, it should be noted that this study is somewhat limited because it was cross-sectional in design, so the presence or otherwise of a causal relationship could not be established. In addition, the sample covered a narrow age range. Also, several variables such as dietary intake, physical activity and maturity stages were collected via self-completed questionnaire, which may be a limitation due to the potential for misreporting. However, no method is without its limitations and this method was pilot tested on adolescents, it was expected that it would be a reasonable approach. First, seven-day dietary record seemed the most appropriate in view of adolescents memory processing capability[30] and because other approaches such as indirect calorimetry were not possible in this population-based study. Second, the translated PAQ-C had previously been validated in a local setting.[40] Third, the self-reported puberty stage has been found to be reliable in a school-based survey with a weighted kappa coefficient of 0.68 for males and females.[62]

CONCLUSION

The findings of this study suggest that muscle strength is associated with energy intake and physical activity among males. However, this relationship was not found in females. This difference requires further investigation in order to gain better understanding of the issues affecting muscle strength so as to improve the provision of nutritional and physical activity strategies for the adolescent muscular health of both genders.

ABBREVIATIONS

BMI Body Mass Index

IQR Interquartile range

Acknowledgments: The authors would like to thank Associate Professor Dr. Mohd Nahar Azmi Mohamed, Professor Dr. Tin Tin Su and Dr. 'Abqariyah Binti Yahya for the support and guidance.

Contributors: AK Ng, HA Majid and NN Hairi carried out the data analysis. AK Ng drafted the manuscript. HA Majid and MY Jalaludin contributed in the design of the study and data collection. All authors contributed to the final manuscript write up.

Funding: This study was supported by funding received from the University Malaya's Research Programme (UMRP022A-14HTM) and Postgraduate Research Fund (PG026-2016A).

Competing interests: None.

Ethical approval: Ethics Committee of the University Malaya Medical Centre (MEC Ref. No. 896.34).

Data availability statement: All data relevant to the study are included in the article or uploaded as supplementary information.

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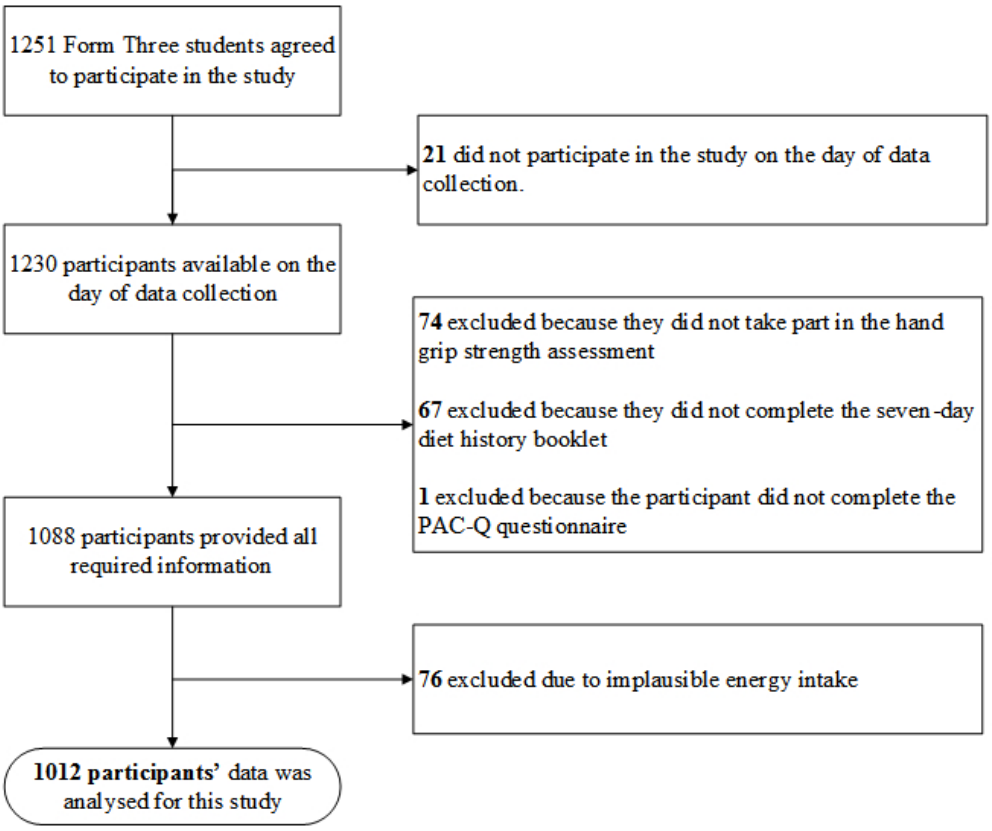

Flowchart of the participant sampling procedure

173x143mm (96 x 96 DPI)

STROBE 2007 (v4) checklist of items to be included in reports of observational studies in epidemiology*

Checklist for cohort, case-control, and cross-sectional studies (combined)

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	1
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	3
Objectives	3	State specific objectives, including any pre-specified hypotheses	3
Methods			
Study design	4	Present key elements of study design early in the paper	4
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	4
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	4
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	Not applicable
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	4-5
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	4-5
Bias	9	Describe any efforts to address potential sources of bias	Not applicable
Study size	10	Explain how the study size was arrived at	4
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	6
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	6
		(*b*) Describe any methods used to examine subgroups and interactions	6
		(*c*) Explain how missing data were addressed	Not applicable
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed	Not applicable

		Cross-sectional study—If applicable, describe analytical methods taking account of sampling strategy	
		(*e*) Describe any sensitivity analyses	Not applicable
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	6
		(b) Give reasons for non-participation at each stage	6
		(c) Consider use of a flow diagram	Not applicable
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	6, 8-9
		(b) Indicate number of participants with missing data for each variable of interest	6
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	Not applicable
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	Not applicable
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	Not applicable
		Cross-sectional study—Report numbers of outcome events or summary measures	Not applicable
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	6-7, 10
		(*b*) Report category boundaries when continuous variables were categorized	Not applicable
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	Not applicable
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	Not applicable
Discussion			
Key results	18	Summarise key results with reference to study objectives	11-13
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	13
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	13
Generalisability	21	Discuss the generalisability (external validity) of the study results	13
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	14

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

Dietary intake, physical activity and muscle strength among adolescents: the Malaysian Health and Adolescents Longitudinal Research Team (MyHeART) study

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2018-026275.R3
Article Type:	Research
Date Submitted by the Author:	31-May-2019
Complete List of Authors:	Ng, Ai Kah; University of Malaya, Faculty of Medicine, Department of Social and Preventive Medicine; International Medical University, School of Health Sciences, Nutrition and Dietetics Department Hairi, Noran; University of Malaya, Faculty of Medicine, Centre for Epidemiology & Evidence-Based Practice and Department of Social and Preventive Medicine Jalaludin, Muhammad Yazid; University of Malaya, Faculty of Medicine, Department of Paediatrics Majid, Hazreen; University of Malaya, Faculty of Medicine, Department of Social and Preventive Medicine; Harvard University T H Chan School of Public Health, Nutrition
Primary Subject Heading:	Public health
Secondary Subject Heading:	Paediatrics, Nutrition and metabolism
Keywords:	Hand grip strength, Dietary intake, Adolescents, Physical activity, muscle strength

Research article

Dietary intake, physical activity and muscle strength among adolescents: the Malaysian Health and Adolescents Longitudinal Research Team (MyHeART) study

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Word Count, excluding title page, abstract, references, figures and tables: 4000 words.

Tables: 3

Figure: 1

Funding Statement: This study was supported by funding received from the University Malaya's Research Programme (UMRP022A-14HTM) and Postgraduate Research Fund (PG026-2016A).

Funding

University of Malaya Research Grant (UMRP022A-14HTM), UMSC grant cycle 1-2016 and all the school children who participated in this study. The funding bodies did not contribute to the design of the study, data collection, analysis, or interpretation of data.

Disclosure: The authors declare that they have no conflict of interests.

Author Contributions/ Statement of authorship: AK Ng, HA Majid and NN Hairi carried out the data analysis. AK Ng drafted the manuscript. HA Majid and NN Hairi contributed in the design of the study. HA Majid and MY Jalaludin involved with the data collection. All authors contributed to the final manuscript write up.

Ethics approval and consent to participate

Ethical approval was obtained from the Medical Ethics Committee, University Malaya Medical Centre (MEC Ref. No: 896.34). The National Medical Research Register number is 14-376-20486. Participation in the study was voluntary and written informed consent and ascent for participation in the study was obtained from the parents or guardian as well as the participants.

Title: Dietary intake, physical activity and muscle strength among adolescents: the Malaysian Health and Adolescents Longitudinal Research Team (MyHeART) study

ABSTRACT

Objective: To examine the role of dietary intake and physical activity in muscle strength among adolescents.

Design: Cross-sectional analysis.

Setting: The Malaysian Health and Adolescents Longitudinal Research Team (MyHeART) study.

Participants: Fifteen-year-old secondary school children who have given consent and who participated in the MyHeART study in 2014.

Primary outcome measure: Muscle strength was measured in relation to dietary intake (energy and macronutrients) and physical activity by using a hand grip dynamometer.

Results: Among the 1012 participants (395 male; 617 female), the hand grip strength of the males was higher than that of the females (27.08 kg vs 18.63 kg; $p<0.001$). Also, males were more active (2.43 vs 2.12; $p<0.001$) and consumed a higher amount energy (2047 kcal vs 1738 kcal, $p<0.001$), carbohydrate (280.71 g vs 229.31 g; $p<0.001$) and protein (1.46g/kgBW vs 1.35g/kgBW; $p<0.168$). After controlling for ethnicity, place of residency and body mass index (BMI), there was a positive relationship between hand grip strength and the intake of energy ($r=0.14$; $p=0.006$), carbohydrate ($r=0.153$; $p=0.002$) and fat ($r=0.124$; $p=0.014$) and the physical activity score ($r=0.170$; $p=0.001$) and a negative relationship between hand grip strength and the intake of protein ($r=-0.134$; $p=0.008$), for males. However, this was not observed among females.

Conclusions: Energy, carbohydrate and fat intakes and physical activity score were positively correlated with hand grip strength while protein intake was negatively correlated with hand grip strength in males but not in females.

Keywords: Muscle strength, Hand grip strength, Dietary intake, Physical activity, Adolescents

ARTICLE SUMMARY

Strengths and limitations of this study

- The main strengths of this study are that it used a large sample of adolescents and the standardised measurement of muscle strength.
- This study is also the first to investigate the association between dietary intake, physical activity and muscle strength among adolescents in Asia.
- The main limitations of this study are that the sample covers a limited age range and the cross-sectional design of the study does not allow any causality interpretations.

INTRODUCTION

Recent research has paid much attention to poor muscles strength among adolescents and its association with adverse health-related outcomes, including cardiovascular disease,[1] poorer metabolic profile,[2-4] obesity[5 6] and musculoskeletal pain[7] as well as premature death from any cause.[1] Furthermore, a cross-sectional study among adolescents in a city in southern Brazil reported a prevalence of low muscle strength of 47% among the study population.[8] Moreover, most studies have suggested that there is a declining trend of muscle strength among adolescents over time[9-12] except for a study conducted in Colombia[13] that indicated otherwise. The study in Colombia, a middle-income country, also found that, adolescents have a lower hand grip strength compared to those in high-income countries.[13] Similarly, a preliminary finding from the MyHeART study showed that Malaysian adolescents have a lower handgrip strength than those in other countries.[9 14 15] However, it was not possible to categorise the hand grip strength of Malaysian adolescents based on the cutoff values used[8] as there were no available normal values for Asian adolescents. Moreover, the published cutoff values should not be used as the reference standard for Asian populations because most Asians are not able to achieve the published cutoff values.[16]

Issues pertaining to unhealthy dietary intake[17] and low physical activity[18] among adolescents are well documented worldwide,. In fact, dietary intake and/or low physical activity are increasingly recognised to be modifiable health-related behavioural determinants of muscle strength among adolescents.[15 19-21] the results reported by population-based cohort studies regarding the effect of energy and macronutrient intake are limited at this point in time.[15 22] For instance, a cross-sectional study that was conducted among European adolescents found that specific amino acids are associated with muscle strength; however, when carbohydrate is controlled for, these relationships disappear. [15] Another cohort study from India in which pregnant women and children were given a balanced protein-calorie supplementation and the children were followed up at adult stage, also emphasised the importance of an adequate energy intake in order to increase muscle strength. The cohort study also found that energy intake and physical activity are positively associated with muscle strength.[22] Furthermore, an experimental study on adolescents found that milk supplementation with resistance training does not change body composition.[23] However, the authors argued that it could be due to energy intake playing a vital role in the relationship between body composition, resistance training and the effect of these factors on both muscle mass and strength.[23]

In view of the changes that take place in the skeletal muscle in response to energy and macronutrient intake particularly carbohydrate and protein intake, in normal physiology[24], it is worthwhile to further investigate the relationship between dietary intake, particularly energy and macronutrients, and muscle strength. While previous studies have provided some evidences to

demonstrate that low level of physical activity[8 25] and being overweight[8] are associated with low hand grip strength, there was only a study by Gracia-Marco et al (2017) has evaluated the effect of amino acids (dietary protein) and physical activity on hand grip strength. [15] It seems that no study have evaluated the influence of dietary intake and physical activity on hand grip strength among adolescents specifically. Thus, the relationship between dietary intake, physical activity and muscle strength among adolescents is not yet well understood. Moreover, to the best of the authors' knowledge, only a limited number of studies have investigated the association between hand grip strength, dietary intake and/or physical activity among adolescents, particularly in Asia. Therefore, the purpose of this paper is to examine the association between hand grip strength, dietary intake and physical activity among adolescents in Malaysia.

METHODS

This cross-sectional study is a secondary analysis of data derived from the first follow-up of the Malaysian Health and Adolescents Longitudinal Research Team (MyHeART) study. The population for the current study was comprised of 15-year-old adolescents attending public secondary schools in the central and northern regions of Peninsular Malaysia. The sampling method used was multistage random sampling. The primary sampling units were the schools and the secondary sampling units were the students. In the first stage, the study frame was a complete list of public schools in the two above-mentioned regions from which total of 15 public secondary schools were selected. In the second stage, the defined study population was selected from a complete list of Form Three students in each of the selected school. Full details of the original MyHeART study protocol have been published elsewhere.[26]

An information sheet and consent forms were given to the students and their parents/guardian prior to recruitment. Participation in the study was on a voluntary basis. In 2014, 1230 adolescents were recruited for the MyHeART study. Out of the total participants in 2014, 1012 (82.3%) were included in the analysis for this paper. A flowchart of the sampling procedure used to select the participants for this study is provided in Figure 1.

The MyHeART study was approved by the Ethics Committee of the University Malaya Medical Centre (MEC Ref. No. 896.34). Subsequently, formal approval was obtained from the Ministry of Health and Ministry of Education and then approval was sought from the relevant state level administrative authorities before approaching the Headmasters and Headmistresses of the selected schools.

The data collection was conducted by the MyHeART team, which was led by the principal investigator. The team consisted of 20 research assistants (medical doctors, nurses and dietitians) who collected the data at various stations such as anthropometry, hang grip strength and dietary

stations. The data was collected between March and May in 2014. Prior to conducting data collection, Principle Investigator provided orientation and training sessions for the research assistants in order to familiarise them with the objectives and methodology of the study as well as hands-on practice in measuring the anthropometrics and hand grip strength. In addition, the researcher assistants who were dietitians received training on how to conduct the seven-days diet history using standardised portion of food and how to translate the diet history into a coding sheet in order to ensure the consistency and quality of the collected data.

Muscle strength

Hand grip strength has been shown to have moderate to strong validity and high reliability in tests for upper body and lower body strength in adolescents.[27] Moreover, hand grip strength has been found to be valid, reliable and feasible for school setting.[28] Therefore muscle strength was assessed by using hand grip strength. A calibrated hand dynamometer (Jamar, Sammons Preston Rolyan, Illinois, US), whose unit of measurement is the kilogram, was used in the assessment of hand grip strength. The strength of the dominant and the non-dominant hand was recorded. Prior to the measurements being taken, the dynamometer was calibrated. Then, it was adjusted for different hand sizes. Participants were gathered in a hall. . The hand grip strength measurement was taken in the morning before afternoon (between 10 am to 12 pm). Each participant was positioned in a straight back chair with both feet flat on the ground. The elbow was flexed to 90^{o} with forearm and wrist were in neutral position. The measurement began with dominant hand once the dominant hand was identified. The measurement followed by the non-dominant hand. The dominant and non-dominant hands of the participants were each tested three times and the readings were recorded to the nearest 0.1 kg.[29] The average of the three readings for the dominant hand was used in analysis. All the measurements were done by trained research assistants.

Dietary intakes

Dietary intake was assessed by using a 7-day diet history. The diet history is the best method by which to estimate adolescents' intakes because they can better recall what they have eaten and drunk and this history can thus reveal more accurate information about their overall intakes.[30] This method also shows less variation in dietary assessment from the epidemiological perspective[31] and is more representative of adolescents' habitual intakes than other methods.[32 33] The seven-day diet history was collected by trained research assistants who were qualified dietitians. The *Nutrient Composition of Malaysian Food* (4th edition)[34] was used to calculate energy and macronutrient intakes and the values were entered into the Nutritionist ProTM database (Axxya Systems, USA).[34] The intakes from food items and recipes that could not be found in the *Nutrient Composition of Malaysian Food* were calculated on the basis of the details provided by the food packaging and the recipe. These calculations were then entered into the database by adjusting them based on standard recipes (per serving size). After the diet history had been analysed, 10% of the data was randomly cross-checked by an independent qualified dietitian who was not involved in analysing the dietary data. The margin of error was 4.4%. It was seemed acceptable as it has been stated that

a 10% margin of error is acceptable.[35] Total of 76 participants with implausible energy intakes (<500 kcal/day or >5000 kcal/day) were excluded from this analysis.[36]

Physical activity score

A Malay version of the validated physical activity questionnaire for older children (PAQ-C) consisting of 10 items was used to obtain the physical activity level of the adolescents over the past 7 days. The PAC-Q questionnaire has been shown to be valid and to have good internal consistency.[37-39] The translated version has been validated in a local setting. [40] The first item in the questionnaire was used to assess the type and frequency of sports and/or dance activities in which the adolescents took part. The second to eighth were used to assess the activity of the adolescents during physical education classes, recess, lunchtime, immediately after school, in the evenings, at the weekend and during leisure time. A five-point Likert scale 1 [lowest] to 5 [highest] was used for the second to eighth items. The ninth item was used to assess their physical activity frequency. The tenth item was used to gather information on any unusual activities that the adolescents undertook during those 7 days. The results obtained from the PAQ-C were categorised following Crocker et al (1997) into low (<2.33), moderate (2.33-3.66) and high (>3.66).[41]

Anthropometric measures

Body weight was measured by using a digital electronic weighing scale (Seca 813, Seca, UK) and recorded to the nearest 0.1 kg. Height was measured without socks and shoes by using a calibrated vertical stadiometer (Seca Portable 217, Seca, UK) and recorded to the nearest 0.1 cm. Body mass index was calculated as weight in kilograms divided by the square of height in metres. Waist circumference (midpoint between the lowest rib margin and the iliac crest) was measured by using a non-elastic measuring tape (Seca 201, Seca, UK) and recorded to the nearest 0.1 cm. Percentage body fat was measured by using a bioelectric impedance analyser (SC-240, Body Composition Analyser, Tanita Europe BV, The Netherlands).

Sociodemographic measures

Sociodemographic measures were collected via parental and student questionnaires which included questions on age, ethnicity and place of residency.

Statistical analyses

Analyses were performed using the Statistical Package for Social Sciences software for Windows version 22.0 (IBM, Chicago, IL, USA) and the significance level was set at $p<0.05$. The analyses were performed separately by gender. Normality and skewness tests were used to assess normal distribution. All variables showed a normal distribution, except for weight, waist circumference and BMI. Data was presented as means and standard deviations for normally distributed

continuous variables, medians and interquartile ranges (IQRs) for non-normally distributed continuous variables and percentages for categorical variables. The independent t-test was used to examine gender differences for normally distributed variables and the Mann-Whitney U test was used for non-normally distributed variables. The association between hand grip strength and (i) energy intake, (ii) macronutrient intake and (iii) physical activity score was assessed by using Pearson's correlation coefficient. The hand grip strength of the dominant hand was entered as the dependent variable and (i) energy and macronutrient intake and (ii) physical activity score were entered as the independent variables while controlling for ethnicity, place of residency and BMI. Body mass index was chosen as the covariate despite there being several other indicators of obesity because BMI is able to discriminate body fatness in adolescents.[42] In addition, linear regression was used to investigate whether dietary intake and physical activity could predict hand grip strength when controlling for ethnicity, place of residency and BMI.

Patient and public involvement

This is a prospective adolescent cohort study from general population, therefore no patient involvement in this study. In this study, all eligible students were briefed on the purpose of the study, the benefits of the study and any potential harm for them. The individual results such as weight, height, waist and hip circumference and hand grip strength were recorded into individual health information leaflet and this information was given back to the students on the same day of data collection. Once other results on full blood counts, renal profile, fasting blood glucose and lipid profile returned to the investigators, the results were verified by a paediatrician and disseminated to the students' parents. Any of the results that went beyond the clinical reference ranges, the student and parents were informed and referred to either the nearest government clinic or University of Malaya's outpatient paediatric clinic for further treatment. Besides that, study findings will be disseminated through media interview, printed media and presentation to Ministry of Education and Ministry of Health, Malaysia.

RESULTS

Descriptive analysis

Table 1 provides the characteristics of the participants. It can be seen that males had significantly higher values than females in terms of weight, physical activity score, hand grip strength of both hands, and energy and carbohydrate intakes per day, but not in percentage body fat and BMI ($p<0.05$). About two thirds (69.2%) of the females had a low physical activity score, whereas almost two thirds of the males (65.2%) had a moderate to high physical activity score.

Correlation and regression

Table 2 illustrates the main result and the number of participants used for the analysis which was as described in Figure 1. A positive linear relationship was found between energy, carbohydrate,

and fat intakes and physical activity score and the dependent variable hand grip strength ($p<0.01$) among males. Meanwhile, protein (g/kg body weight) was found to be negatively correlated with hand grip strength among males ($p<0.01$). However, no such correlation was found in females.

To investigate whether dietary intake and physical activity could predict hand grip strength, a linear regression was computed while controlling for ethnicity, place of residency and BMI. Before running the regressions, the assumptions of linearity, normally distributed errors and non-correlated errors were checked and met. Protein, carbohydrate and fat intakes were not used in the regression due to multicollinearity. When the physical activity score and energy intake were added, both variables significantly predicted hand grip strength: $F(3, 391) = 26.318$, $p<0.001$, adjusted $R^2 = 0.162$ (Table 3). When physical factors (length of dominant hand span and height) were entered, the prediction improved with an adjusted R^2 of 0.339.

Table 1: Characteristics of MyHeART participants

		Male (n=395)	Female (n=617)	All (n=1012)	*p*
Age (y)		15.04 (±0.198)	15.04 (±0.205)	15.04 (±0.202)	0.384
Ethnicity					
	Malay	307 (77.7%)	487 (78.9%)	795 (78.6%)	0.495
	Chinese	26 (6.6%)	47 (7.6%)	73 (7.2%)	
	Indian	35 (8.9%)	54 (8.8%)	89 (8.8%)	
	Others	27 (6.8%)	29 (4.7%)	56 (5.5%)	
Place of residency					
	Urban	216 (54.7%)	367 (59.5%)	583 (57.6%)	0.132
	Rural	179 (45.3%)	250 (40.5%)	429 (42.4%)	
Weight[a] (kg)		*51.00 (17.00)*	*48.50 (15.35)*	*49.50 (15.60)*	<0.001*
Height (cm)		163.20 (±6.76)	154.65 (±5.67)	157.99 (±7.40)	0.052
BMI[a] (kg/m2)		*18.90 (5.49)*	*20.25 (5.74)*	*19.74 (5.73)*	<0.001*

BMI category				<0.001*
	Underweight	86 (21.8%)	108 (17.5%)	194 (19.2%)
	Normal	222 (56.2%)	355 (57.5%)	577 (57.0%)
	Overweight	51 (12.9%)	101 (16.4%)	152 (15.0%)
	Obesity	36 (9.1%)	53 (8.6%)	89 (8.8%)
% body fat		15.50 (±11.02)	29.37 (±9.17)	23.95 (±12.01)	<0.001*
Waist circumference[a] (cm)		*67.90 (15.50)*	*69.00 (13.50)*	*68.50 (14.00)*	0.514

Differences between male and female participants were determined using an independent t-test and the Mann-Whitney test. Data are presented as means ± standard deviation or as n (%), unless otherwise stated.

**Statistically significant at p<0.05.*

[a]*Values are expressed as medians (IQRs).*

Table 1: Characteristics of MyHeART participants (cont…)

	Male (n=395)	**Female (n=617)**	**All (n=1012)**	***p***
Physical activity score	2.43 (±0.75)	2.12 (±0.54)	2.24 (±0.65)	<0.001*
Physical activity level				
low (<2.33)	177 (44.8%)	427 (69.2%)	604 (59.7%)	<0.001*
moderate (2.33-3.66)	199 (50.4%)	183 (29.7%)	382 (37.7%)	
high (>3.66)	19 (4.8%)	7 (1.1%)	26 (2.6%)	
Hand grip strength (kg)				
Average hand grip strength (dominant hand) (kg)	27.25 (±7.16)	18.73 (±4.63)	22.06 (±7.09)	<0.001*
Average hand grip strength (non-dominant hand) (kg)	25.77 (±7.34)	17.44 (±4.72)	20.69 (±7.15)	<0.001*
Energy & macronutrients intake				
Energy (kcal)	2047 (±583)	1738 (±474)	1858 (±540)	0.001*

Protein (g)	75.69 (±22.48)	66.07 (±19.45)	69.82 (±21.20)	0.04*
Protein (g/kg)	1.46 (±0.58)	1.35 (±0.53)	1.40 (±0.55)	0.168
Carbohydrate (g)	280.71 (±90.17)	229.31 (±67.79)	249.37 (±81.23)	<0.001*
Fat (g)	68.97 (±21.74)	61.60 (±20.13)	64.48 (±21.07)	0.16

Differences between male and female participants were determined using an independent t-test and the Mann-Whitney test. Data are presented as means ± standard deviation or as n (%), unless otherwise stated.

**Statistically significant at p<0.05.*

[a]*Values are expressed as medians (IQRs).*

Table 2: Partial correlation (r) between dietary intake, physical activity score and hand grip strength in adolescents

	Hand grip strength for males* (n = 395)		Hand grip strength for females* (n = 617)	
	r	**P**	**r**	**p**
Energy and macronutrients intake				
Energy (kcal)	0.140	0.006**	0.018	0.651
Protein (g/kg)	-0.134	0.008**	-0.021	0.610
Carbohydrate (g)	0.153	0.002**	0.026	0.528
Fat (g)	0.124	0.014**	-0.002	0.962
Physical activity score	0.170	0.001**	0.042	0.298

**Controlled for ethnicity, place of residency and BMI*

***Statistically significant at p<0.05.*

Table 3: Multiple linear regression model for male adolescents

	Hand grip strength of male (n = 395)		
	R^2	**β**	**p**
	0.162		
Energy intake (kcal)		0.143	0.002*
Physical activity score		0.129	0.006*

**Controlled for ethnicity, place of residency and BMI*

DISCUSSION

Hand grip strength, dietary intake and physical activity

This study showed that the muscle strength of Malaysian adolescents is much lower than that of their counterparts as reported by studies in Europe (males: 35.9±9.3kg; females: 26.2±4.9kg), the United Kingdom (males: 25.7±kg; females: 21.8±5.8kg) and Colombia of South America (males: 33.6±6.85kg; females: 24.9±4.29kg).[2 15 43] Also, according to the results, female adolescents in Malaysia have lower muscle strength than those in Beijing, China.[44] Unfortunately, there is no large population based Asian male adolescent data with which to compare with the results of the current study. Hence, this study can be considered the first documented muscle strength study among adolescents of both genders in Asia. Nevertheless, despite the lack of comparable studies, the trend for adolescents is similar to that reported for Malaysian adult population, where it was found the hand grip strength of Malaysian adults is 1.5 times lower than that of adults in Western countries.[45] Thus together with the findings of the current study, this may indicate that the muscle strength of the Malaysian population is relatively low from a young age. Indeed, the results of a longitudinal study conducted in Quebec, a province in eastern Canada, which tracked muscle strength from childhood to adulthood, suggested that low muscle strength can persist from childhood through adolescence and into adulthood.[46] Therefore, it seems worthwhile to detect low muscle strength at a young age and build it up in order to foster favourable health outcomes in later life.[1] Thus, it can be argued that low muscle strength among adolescents warrants particular attention in order to identify the root cause, especially if it is associated with dietary intake and physical activity which are both modifiable health-related behaviours.

The results of this study also showed that there were differences in hand grip strength, dietary intake and physical activity score between male and female adolescents. Specifically, the males

had higher muscle strength, consumed more energy, protein and carbohydrate and were more physically active than their female counterparts. These findings are consistent with those of previous studies conducted on study populations aged 13 years-old.[14 47 48]

Association between dietary intake, physical activity and hand grip strength

In this study, in males, energy, carbohydrate, and fat intakes and physical activity score were positively correlated with hand grip strength, but protein was negatively weak correlated (table 2). Although it has been shown that protein helps muscle protein synthesis and thus eventually improves muscle strength[49], the effect of protein was not observed in this study. One possible explanation for this finding could be due to quality of protein consumed.[50] Often, dietary protein is ingested as a whole so it includes high biological value and low biological value and this leads to difficulty in identifying how proteins derived from animal and plant sources differ in their capacity to improve muscle mass and strength. Empirical studies have shown that at least 25 g of high quality proteins (including at least 8-10 g essential amino acids and higher leucine content) promote muscle protein synthesis and thus result in better muscle strength.[49] Therefore, the specific impact of high biological value protein is worth investigating in the future.

In addition, studies have also reported that energy plays a moderating role in muscle strength.[22 23] Although a study that used milk supplementation and resistance training as an intervention did not see an improvement in muscle mass, the researchers argued that energy plays a mediator role in the relationship between muscle mass, protein intake and resistance training despite the finding showing otherwise.[23] Therefore, a sufficient intake of energy and/or carbohydrate to meet the daily requirement is needed before protein can play a role in promoting muscle building and strength.

In the current study, when the energy intake per day and physical activity score were added into the model while controlling for BMI, both of these predictors remained significantly associated with hand grip strength. In addition, a higher energy intake and a higher physical activity score predicted a higher hand grip strength. Moreover, a higher BMI predicted a higher hand grip strength. The latter finding is consistent with that reported by a study on Southern Brazil adolescents, which found that the higher the BMI the greater the muscle strength.[21] Also, the researchers stated that their study population had a higher body mass, particularly muscle. As the current study did not include an objective measure for muscle mass, we considered body fat percentage and it was found that the male participants had a lower body fat percentage than the female participants. In addition, the average BMI of the (15-year-old) male participants was below the overweight level using International Obesity Task Force reference. Nevertheless, BMI is not generally regarded as a good indicator of body composition.[51] In this study, body fat percentage showed similar result after percentage body fat was used in the model to replace BMI. With that, the usage of BMI remained for easier comparison to other studies. On the other hand, there is a general consensus that the higher the body fat, especially abdominal fat, the lower the hand grip

strength.[5] This could be due to fat playing an inert role in muscle strength.[52] However, in contrast to the above-mentioned studies, a study conducted in Italy on a sample of 2411 adolescents produced a neutral result, implying that obesity does not affect muscle strength among healthy schoolchildren.[53] Nonetheless, the predictive equation used in the current study needs to be interpreted with caution as energy intake and physical activity only explain about 16.2% of the variation in muscle strength.

In this study, no relationship was found between dietary intake, physical activity score and hand grip strength among female adolescents. This result is similar to that reported in a study on adolescents in Europe[15], which showed that proline (amino acids) is positively correlated with lower limb muscular strength but that, when carbohydrate intake is controlled for, this relationship disappears.[15] On the other hand, a study conducted among Kenya adolescents found that female adolescents have greater muscle strength than their male counterparts and suggested that thi was because the females undertake more household chores such as transferring water from deep wells and preparing meals, and thus have greater access to food than the males.[54] All such activities eventually help to build upper limb muscle strength. However, these conditions are not commonly found in Malaysia where most adolescents are school attendees. It is therefore postulated that the reason that female adolescents in this study had lower muscle strength than the males is because almost 70% of the females had a low physical activity score due to a predominantly sedentary lifestyle as compared to the males, 65% of whom had a moderate to high physical activity score. It has also been found by a previous study that females already have a lower physical activity score at an earlier age compared to males[47] and that this continues as they age.

Another possible reason for the significant result observed in males but not females could be due to changes with puberty stage, where the hand grip strength of males increases tremendously at this stage as compared to females. A study has reported that at 13 years old, the hand grip strength of males and females is 17.8 kg and 14.7 kg, respectively[14]. Greater muscle hypertrophy is commonly found in pre-adolescent males compared with females at the same growth stage because of increasing levels of circulating androgens in the males.[55] Moreover, it has also been found that muscle strength increases when a male reaches puberty, which it has been argued is related to the growth spurt due to the direct action of testosterone, which has a direct anabolic effect on muscle fibres.[56] In the population analysed in the current study, the majority (95%) of the males has reported that they had reached the puberty stage. Thus, in addition to the males being moderately to highly physically active, the presence of testosterone could explain the marked difference in muscle strength between the male and female participants.

Although a positive effect of protein on muscle strength was not seen in this study, it is still crucial to explore the effect of dietary protein as it is known to play a role in ensuring appropriate growth during adolescence.[15] Furthermore, muscle building only occurs when a person is physically active because such activity triggers the digestion and better absorption of amino acids,[50 57] which

eventually increases muscle strength. Moreover, it is crucial to ensure that energy and carbohydrate intake requirements are met before protein can even play a role in improving muscle strength. The above findings therefore indicate that there is a strong need to undertake a longitudinal study to explore whether changes in dietary intake have an impact on hand grip strength among adolescents, and such a study also needs to takes into account the variables of physical activity and weight status.

It is also important to acknowledge that the type of physical activity can affect the hand grip strength. A cross-sectional study has suggested different types of physical activity influence hand grip strength and not the amount of time spent on physical activity.[58] Often, studies on muscle strength have included obesity parameters such as BMI and percentage body fat. Some of these studies have found that obese adolescents exhibit lower relative muscle strength to body mass as compared to their non-obese counterparts.[6 52] Some studies have found otherwise.[8 53 59] For instance, one such study reported that girls with normal BMI have a low hand grip strength as compared to overweight/obese girls,[8] and the author postulated that the overweight/obese females may have increased their muscle mass due to physical growth. However, this findings and postulation needs to be interpreted cautiously because BMI does not differentiate between fat mass and fat-free mass. Moreover, the finding of that study could be due to discrepancies when examining the absolute strength and muscle strength relative to muscle mass and muscle quality. Besides dietary and physical activity factors, the literature has also shown that physical factors such as height and length of hand span can influence hand grip strength.[21 60 61] Although assessing the influence of physical factors was not one of this study's objectives, physical factors were found to play a role in influencing hand grip strength.

Strengths and limitations

This study has a number of strengths. Firstly, it was conducted using a large sample of adolescents. Secondly, it used the standard protocols for hand grip strength, dietary intake and physical activity assessment as well as data monitoring processes during data collection, data entry and data analysis in order to minimise the risk of bias. Moreover, to the best of the authors's knowledge, this study may be the first to investigate the association between hand grip strength, dietary intake and physical activity among adolescents in Asia. However, it should be noted that this study is somewhat limited because it was cross-sectional in design, so the presence or otherwise of a causal relationship could not be established. In addition, the sample covered a narrow age range. Also, several variables such as dietary intake, physical activity and maturity stages were collected via self-completed questionnaire, which may be a limitation due to the potential for misreporting. However, no method is without its limitations and this method was pilot tested on adolescents, it was expected that it would be a reasonable approach. First, seven-day dietary record seemed the most appropriate in view of adolescents memory processing capability[30] and because other approaches such as indirect calorimetry were not possible in this population-based study. Second, the translated PAQ-C had previously been validated in a local setting.[40] Third, the self-reported

puberty stage has been found to be reliable in a school-based survey with a weighted kappa coefficient of 0.68 for males and females.[62]

CONCLUSION

The findings of this study suggest that muscle strength is associated with energy intake and physical activity among males. However, this relationship was not found in females. This difference requires further investigation in order to gain better understanding of the issues affecting muscle strength so as to improve the provision of nutritional and physical activity strategies for the adolescent muscular health of both genders.

ABBREVIATIONS

BMI	Body Mass Index
IQR	Interquartile range

Acknowledgments: The authors would like to thank Associate Professor Dr. Mohd Nahar Azmi Mohamed, Professor Dr. Tin Tin Su and Dr. 'Abqariyah Binti Yahya for the support and guidance.

Contributors: AK Ng, HA Majid and NN Hairi carried out the data analysis. AK Ng drafted the manuscript. HA Majid and MY Jalaludin contributed in the design of the study and data collection. All authors contributed to the final manuscript write up.

Funding: This study was supported by funding received from the University Malaya's Research Programme (UMRP022A-14HTM) and Postgraduate Research Fund (PG026-2016A).

Competing interests: None.

Ethical approval: Ethics Committee of the University Malaya Medical Centre (MEC Ref. No. 896.34).

Data availability statement: All data relevant to the study are included in the article or uploaded as supplementary information.

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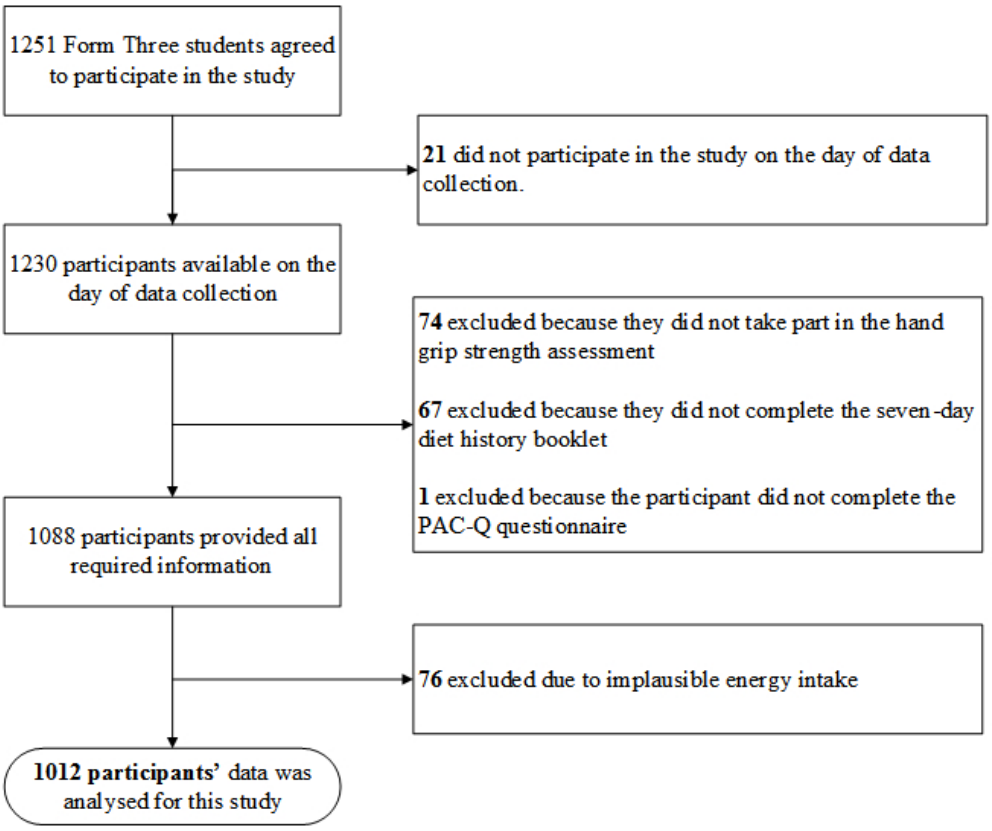

Flowchart of the participant sampling procedure

173x143mm (96 x 96 DPI)

STROBE 2007 (v4) checklist of items to be included in reports of observational studies in epidemiology*

Checklist for cohort, case-control, and cross-sectional studies (combined)

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	1
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	3
Objectives	3	State specific objectives, including any pre-specified hypotheses	3
Methods			
Study design	4	Present key elements of study design early in the paper	4
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	4
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	4
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	Not applicable
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	4-5
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	4-5
Bias	9	Describe any efforts to address potential sources of bias	Not applicable
Study size	10	Explain how the study size was arrived at	4
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	6
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	6
		(*b*) Describe any methods used to examine subgroups and interactions	6
		(*c*) Explain how missing data were addressed	Not applicable
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed	Not applicable

		Cross-sectional study—If applicable, describe analytical methods taking account of sampling strategy	
		(*e*) Describe any sensitivity analyses	Not applicable
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	6
		(b) Give reasons for non-participation at each stage	6
		(c) Consider use of a flow diagram	Not applicable
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	6, 8-9
		(b) Indicate number of participants with missing data for each variable of interest	6
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	Not applicable
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	Not applicable
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	Not applicable
		Cross-sectional study—Report numbers of outcome events or summary measures	Not applicable
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	6-7, 10
		(*b*) Report category boundaries when continuous variables were categorized	Not applicable
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	Not applicable
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	Not applicable
Discussion			
Key results	18	Summarise key results with reference to study objectives	11-13
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	13
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	13
Generalisability	21	Discuss the generalisability (external validity) of the study results	13
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	14

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.
Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.